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Radar Sensing of Petroleum Seepage Gases

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13. ABSTRACT (*Maximum 200 words*)

Simple X-band radars have been used by a number of commercial exploration companies since 1972 in the search for gas and oil deposits. Uncertainty and controversy over the physical mechanism involved in the radar sensing of gas and oil led to the April/May 1992 radar investigation conducted by NRL. A low power X-band radar was used by NRL to acquire experimental data in Texas. The attributes of return signals observed over producing and prospective oil fields were found to have a unique set of characteristics which included the following:return signals were from weak, distributed targets: simultaneous amplitude and range variations were observed (10 dB or more in amplitude and $\pm$ 60 ft in range) within time intervals of 1/3rd second and at ranges of from 500 to 2,000 ft, and at elevation angles of less than $+ 1°$. The range and amplitude varying radar returns were suppressed by rain and/or a wet earth. Also during a single period of 24 hour observation, the varying signals disappeared during a period of high humidity (local night-time) and then re-appeared the next day when the relative humidity dropped below 50%. Radar returns from seepage gases at heights greater than 25 feet as well as gas associated radar returns over cattle feed lots (methane and ammonia) were not confirmed.

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RADAR SENSING OF PETROLEUM SEEPAGE GASES

EXECUTIVE SUMMARY

This report summarizes the results of an investigative effort conducted by the Naval Research Laboratory (NRL) for the AMOCO Production Company (AMOCO) under the terms of a Cooperative Research and Development Agreement (CRDA). The NRL responsibility in this effort was to perform a radar-based investigation on the sensing of seepage gases associated with underground petroleum deposits.

Findings.

Unique radar signals were observed during the course of the NRL radar observations in Texas and New Mexico during April 1992. Important considerations of uniqueness relative to the presence of petroleum products are the following findings:

Radar echoes within a particular established oil field were observed which were characterized by distinctive fluctuations in range and amplitude. These are believed to be characteristic of gas seepage.

Radar measurements at a *potential oil and gas bearing field* detected similar patterns.

The return signals emanated within localized regions where there were no visually identifiable hard targets (man-made or natural such as bushes and trees).

A. The returns of interest were not point targets, but were distributed over an area. An example illustrated in the report covers an area of about 250 by 250 ft.

B. The signals of interest varied in amplitude from the noise threshold to over 10 dB. Radar cross sections within a resolution cell were on the order of 0.01 to 2.1 square meters.

C. The radar returns of interest, in one example exhibited range variations of 60-100 ft. and an amplitude variation of 10 dB within a 0.3 second time interval.

D. The strongest echo fluctuations in amplitude and range observed with the ground-based radar, were returns recorded in the vicinity of producing oil wells near the New Mexico/Texas border.

E. In one test, the unique fluctuating signals diminished and then disappeared with the onset of local hours of darkness. Several hours after sunrise, the varying signals reappeared.

F. Rain and/or wet ground resulted in a cessation of the variable signal activity.

Manuscript approved October 28, 1992

G. Observational evidence (based on the use of the pencil beam antenna) suggests that the radar signal returns are for targets at heights of less than 25 ft.

H. Methane and ammonia from cattle feed lots have been presumed, by other investigators, to have been detected with a helicopter-radar system. The ground-based radar, when targeted against a very large cattle feed lot, was unable to confirm the presence of any unique radar returns.

Caveats.

All of the NRL "statement of work" objectives have been met except those that were impacted by the absence of "ground truth" data. Absent ground truth data specifically included the identification of hydrocarbon gases present during the radar observations, and the helicopter radar video records. The scheduled seepage gas measurements to be provided by AMOCO were not made because of equipment failure and scheduling problems. On several occasions during the data analysis and report preparation period, NRL advised AMOCO of the non-receipt of, and the need for copies of the helicopter radar video records. The subject records up to the time of preparing this report have not been received.

Conclusions.

A. Unique radar returns were observed which suggested that they might be associated with the presence of seepage gases.

B. In one area presumed to have a high level of seepage gases the plan position indicator (PPI) displays for the helicopter-borne and the ground based radars, for a single PPI scan, were judged to be nearly identical. It was judged that the two radars had approximately equal target detection capability for small fixed targets.

C. It was reasoned that the helicopter-radar based declarations of the presence of hydrocarbon gases were based on a discernment of subtle amplitude variations in the PPI display. With the NRL ground based radar, the declarations of the presence of unique radar returns was based on amplitude and range variations in the signals of interest. Further, these variations were more readily detectable with the A-scope falling raster display incorporated in the ground radar system.

D. Based on a comparison of signals received with the fan and the pencil beam antennas it was decided that the unique fluctuating radar returns were from atmospheric cells that did not extend 25 ft above ground.

E. The anecdotal history on the impact of rain on the detectability of seepage gases was confirmed. In that the signals previously observed, were not present immediately after a heavy rain.

RADAR SENSING OF PETROLEUM

SEEPAGE GASES

I. INTRODUCTION

Low power, surface-search marine radars have been used since the early 1970's as an aid in the exploration for oil and gas. In 1972 a patent for the basic concept was issued to Mr. Robert Owen.[1] The subject patent claimed that seepage gases associated with the underground presence of petroleum products were detectable with X-band (3-cm wavelength) radar systems. The patent claimed that the radar signals excited the hydrocarbon gas molecules of the seepage gases. In turn, the excited gas molecules re-radiated r-f energy, at a frequency different than that of the illuminating radar. The frequency-translated radar echo was claimed to be detectable with the radar when the receiver was tuned to a frequency different from that of the transmitter.

In 1986 NRL personnel (Skolnik, Hansen, and Hemenway) met with Owen and observed demonstrations of his system.[2] At that time it was determined that the claim for a frequency translation was not correct. The signals were observed with the radar system receiver tuned to the transmitter frequency, and with the receiver gain control reduced to an un-calibrated low gain level as compared to the setting used for normal radar system operation.

In early 1991, Amoco Production Company (AMOCO), contacted the NRL Radar Division for assistance relative to the application of radars in the exploration for oil.

As originally planned NRL was to visit three areas selected by AMOCO. AMOCO was to have the commercial airborne radar unit operated by Airborne Petroleum Services (APS) present at two locations and a contractor with an Fourier Transform Infra Red (FTIR) system to measure atmospheric gases at all three. As it turned out, the equipment to measure gases was delayed and never was available for gas measurements at any of the sites. It subsequently became available but AMOCO decided not to measure as they wanted measurements made at the same time the radar was present.

The three areas were to include an oil and gas field in East Texas, an undrilled prospect in West Texas, and a microwave benchmark, a feedlot, in Northwest Texas. As the test progressed AMOCO added three additional areas. These included a second undrilled prospect, a second oil and gas field found in the 1950-60's and still active, and an oil and gas field found in 1991 and undergoing development.

Field operations were under the direction of a geological consultant contracted by AMOCO for this project.

The AMOCO/NRL Radar Division discussions led to the initiation of an NRL/AMOCO Cooperative Research and Development Agreement (CRDA).[3] This report fulfills the CRDA Statement of Work calling for the preparation and submission of a summary report on the results of the NRL radar/oil investigation

II. OBJECTIVES

The objectives of the NRL CRDA were for NRL to:

A. Assemble a team of experienced radar personnel, a radar, and instrumentation for duplication of, and possible enhancement of the radar observations made by AMOCO and APS.

B. Deploy the NRL personnel and equipment to Texas for "field" operations and observations with the AMOCO group.

C. Through the use of a modified and augmented X-band radar, to acquire data that would aid in the characterization of the radar returns which might be uniquely associated with the presence of underground petroleum products. To be considered are:

(1) Radar echo signal amplitude, frequency, time history, location, and spatial dimensions.

(2) Correlation with other data. To include: atmospheric temperature, pressure, humidity, wind speed, wind direction, geological data helicopter radar records, and FTIR measurements of atmospheric gases in the NRL radar field of view.

D. Process, analyze, and report on the observed characteristics of the radar returns associated with the presence of petroleum products. The analysis is to include the relation or correlation of other data (meteorology, geology, atmospheric gas analysis, and helicopter radar) with the NRL radar data.

III. APPROACH

Background: The subject investigation was based on the provision by NRL of a 3-person team, which would follow a schedule that allowed for an approximate eight weeks period of preparation, two-weeks of data acquisition in the "field," and 16 weeks for the processing and analysis of data, and the preparation of a summary report. That planned schedule was delayed for a period of several weeks, for reasons of equipment problems experienced by another group.

The radar system was similar to that used by AMOCO/APS. The NRL choice was a Raytheon R-82 radar, an improved successor to the Raytheon PATHFINDER radar system used by APS. See Appendix B for more discussion of the two radars and a listing of system parameters.

To allow for better documentation of the character of the radar return signals of interest, the R-82 was modified and augmented such that:

A. A pencil beam (2.7° beamwidth in azimuth and elevation) antenna was added so that either a fan beam or a pencil beam antenna pattern could be manually selected for the acquisition of data. The fan beam antenna was a slotted array antenna with horizontal and vertical beamwidths of 1.2° and 25° respectively. The equivalent values for the helicopter radar were 3° and 20° (see Appendix B).

The 32-inch diameter parabolic dish antenna provided by NRL provided an approximate 2.7° pencil beam pattern. The pencil beam antenna was selected so as to allow for better resolution of the elevation extent of the radar returns of interest, and for "searchlighting" (constant radar illumination of a volume of space) at specific azimuth and elevation angles.

B. The *Pathfinder* radar as used by APS was *equipped only* with a Plan Position Indicator (PPI). A PPI display uses a map-like circular-coordinate reference system (Fig.1). The display has a rotating strobe, with the center of rotation representing the location of the radar. Distance along the strobe is a measure of range. The azimuth position of the strobe corresponds to the instantaneous bearing of the radiated antenna beam. Intensity of the strobe is representative of the strength of the radar return.

To allow for a better understanding of the dynamics of the signals of interest, NRL modified the R-82 so that the radar video could also be displayed on an A-scope display (Fig. 2). An A-scope display uses a rectangular coordinate reference. Range is indicated by the horizontal axis and signal strength by the vertical axis.

C. Data recording during the investigation was based on combinations of conventional film based cameras, video cameras, computer controlled analog-digital sensors, digital video data sampling, and manual log notation.

System Preparation:

The system was initially assembled and checked out at NRL Building 46. Then the system was dismounted and installed in a mobile-lab. The mobile system was then exercised in the Washington area, in a manner similar to what was planned for Texas field operations and observations. The system as assembled at NRL was not capable of operation with the mobile-lab in motion. Certain elements of the system had to be assembled and connected external to the mobile-lab, when field data was to be acquired. As assembled, the system was capable of operation with its own primary power supply. (In the field, modifications were made which allowed for radar operation while in motion. This later mode of operation was useful for "quick look" evaluations.)

The general disposition of the various elements of the system are shown in Fig. 3, which documents the setup used at SITE 1.

The NRL radar system was installed in a mobile-lab, as pictured in the photograph of Fig. 4. Observations and data acquisition was performed with one or the other of the two antennas mounted on the same pedestal. The physical changeover from one antenna to the other was an approximate 10 minute task.

In Fig. 4, a photograph taken on location at the East Texas SITE 1, the Raytheon array antenna is shown mounted on top of the transmitter-receiver module. That module is in turn mounted on a heavy duty, photographic tripod. The mast to the left (the rear of the mobile-lab) supports the meteorological sensors (temperature, wind speed and direction) and the Global Positioning System (GPS) antenna used to determine precise locations.

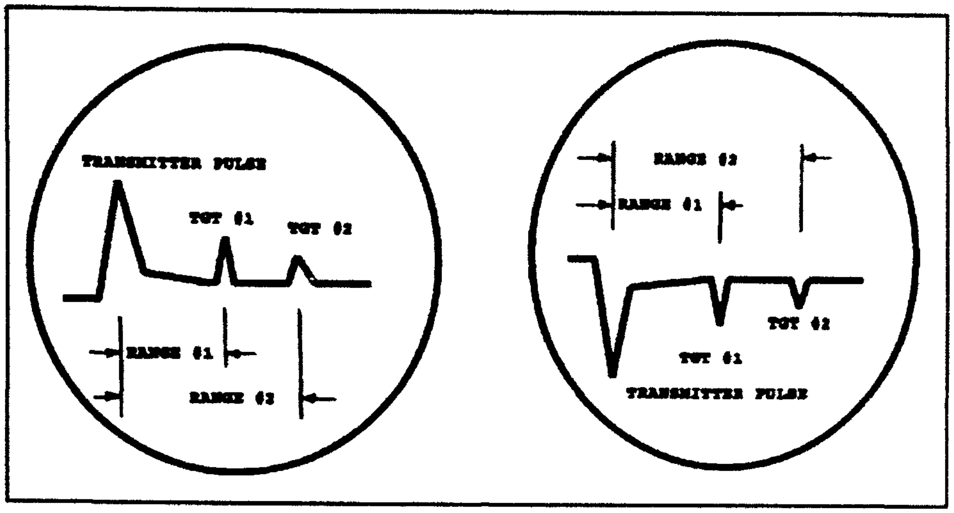

Fig. 1 A PPI or Plan Position Indicator display. Range is measured along a radial from the center of the display.

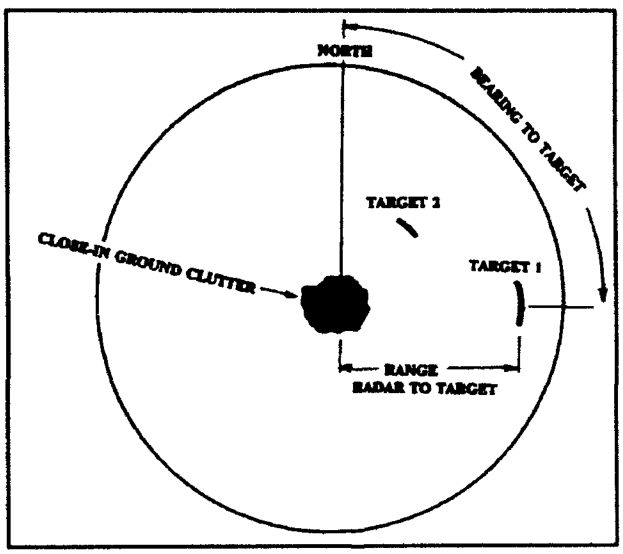

Fig. 2 A-scope displays. Range is measured on the horizontal axis. Signal strength is measured on the vertical axis. The direction of vertical deflection is elective, both displays above are valid representations of the same data.

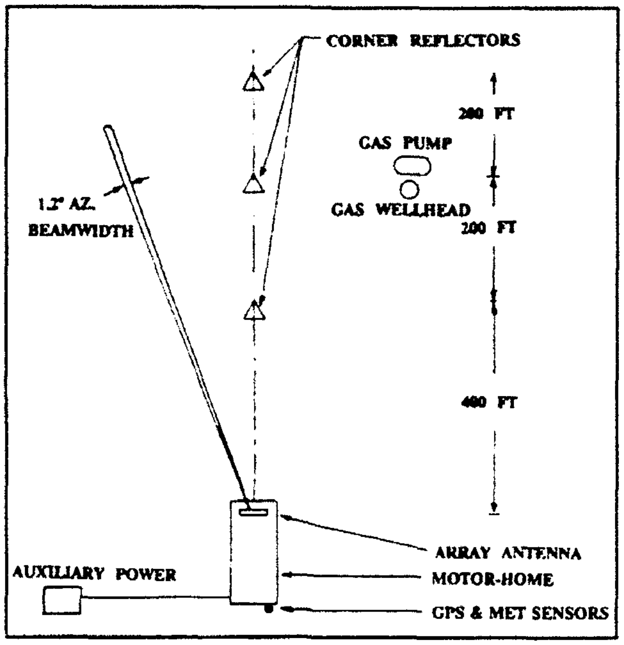

Fig. 3 Plan view showing the relative location of equipment at SITE 1 in East Texas. Note - not to scale.

Towards the end of the deployment period, additional modifications were made, and observations were made with the array antenna attached to the roof of the mobile-lab without the tripod. In this last configuration, data was acquired with the mobile-lab in motion at typical road speeds of 55 mph (48 knots).

IV. FIELD OPERATIONS

In the sections which follow, for the sake of AMOCO proprietary interests, names and locations of specific sites investigated are not revealed. Sites will be referred to by numbers. Data was acquired in three general areas :

East Texas - West Texas - New Mexico/Texas

Appendix A provides detailed information on each of the major sites visited. A brief listing of the sites together with initial impressions follows below:

INITIAL IMPRESSIONS

SITE 1 (Producing Field)

SITE 1 had by previous helicopter surveys (understood to have been December 1991 and March 1992) been identified as an area of high gas seepage. The NRL ground based radar was not able to confirm that there was radar detectable gas seepage, during the two-day period of observations at this location. The area involved had been subjected to heavy rains for several days before the commencement of NRL observations.

The APS radar system at this same time, confirmed that radar detectable signs of seepage gases were no longer discernable in the immediate area of the ground radar. It was claimed that the helicopter radar detected seepage to the Southwest of the ground radar, but at too great a range for observation with the ground based radar.

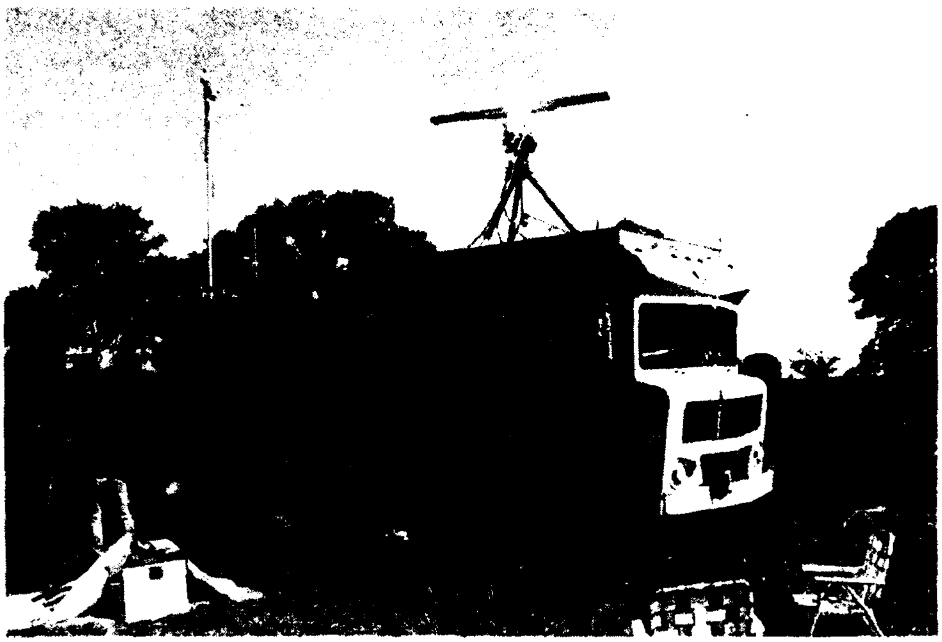

Fig. 4 The mobile-lab used as a carrier-platform for the ground based radar system.

SITE 2 (Undrilled Prospect)

SITE 2, was a second site for which the extent of radar detectable seepage had also changed since the previous helicopter survey. The NRL ground based system did not provide evidence of gas seepage at or within 1/2 nmi of SITE 2. The pencil beam antenna did provide negative data, in the sense that elevated returns were not observed. Unlike SITE 1 where there had been heavy recent rains, SITE 2 was dry. The helicopter radar survey of April 4, 1992, did claim a detection of seepage gases Northwest of Site 2 but not at SITE 2 as had been claimed in the helicopter survey of December 1991.

SITE 3 (Undrilled Prospect)

SITE 3, was within a mile of SITE 2, and closer to a point where moderate radar indications of seepage had been reported for the helicopter survey of April 4, 1992. The ground based operators were unable to confirm the helicopter results. That is, there were not any returns of a nature that would appear to "fit" the scan-to-scan varying return over a wide area.

SITE 4 (Undrilled Prospect)

SITE 4 was the most promising and interesting site visited. This site was in the middle of an area of extensive radar seepage returns, as determined by the helicopter system. The PPI displays for the helicopter and the ground based radar, were judged by the helicopter operator/observer as being nearly identical for the specific terrain and time of day of the observations. Use of the pencil beam provided evidence that the radar returns of interest were not elevated above the nominal 3° elevation beamwidth.

A-scope observations revealed that the returns of interest were at ranges of 700 to 1500 ft. Almost any location within the 700 to 1500 ft range along the 228° azimuth showed amplitude and range variations. The amplitude variation in one example was on the order of 7 dB in amplitude. A range variation of 60 ft at a rate which was measured as about 3 Hz will be reviewed later. PPI observations of the area showed that similar variable responses could be observed over a sector from about the 180° to 220°.

It was at this time, that the NRL observers concluded that the helicopter-radar observers were making judgements on the presence of seepage gases which were based on a perception of the area extent and amplitude the radar clutter. The impression gained from viewing the APS radar video tapes and through discussions with the helicopter radar operator-observer was that a declaration of the presence of seepage gases was based in part on a continuing reference between the airborne radar PPI display and the observers cockpit view of the terrain being overflown. In its simplest form, if the cockpit view was of homogeneous grassland, and the PPI display showed significantly higher clutter levels over an extended area, the operator might then declare that the radar returns from that area were related to seepage gas. If the operator became aware of higher clutter levels on the PPI display, and on reference to the cockpit view, noted that the higher clutter level area coincided with an upward slope of the terrain, the increased clutter level would not be associated with the probable presence of seepage gases.

As will be developed, the NRL ground-based radar system was more capable in a number of performance characteristics than the helicopter radar system. The ability to sense changes in the level of ground clutter was approximately the same for the two radars. Due to instrumentation and the fact that it was operated in motion, the helicopter system was incapable of sensing the small scale range and amplitude changes to clutter areas which could be readily observed with the ground-based radar.

A fortuitous heavy rain storm, resulted in an observation that the highly fluctuating signals from the close-in (ranges of 500 to 1,500 ft) area of interest were greatly affected by the rain. Observations made immediately after the rain, revealed that the overall level of close-in clutter was reduced in magnitude, and further, the amplitudes were stable. These were observations made between 13:00 and 17:00 local time.

Within half an hour of the passing of the rain storm, the signal fluctuations returned approximately to the previously observed levels of amplitude variation.

Two days later on a return to the same operating area, the same fluctuations were again observed. The return visit to SITE 4 was for the purpose of conducting a continuous 24-hour period of observations. A hour after local sunset, the amplitude fluctuations began to subside. Approximately two hours after sunset the amplitude variations were observed to be greatly reduced, and the overall level of close-in clutter (that clutter within a 1/2 nmi radius) was diminished.

Temperature and humidity may well have played a role in the nature of the observed close-in radar returns. The table below indicates how these values changed throughout the 24-hour observation period. Note the typical pattern of changing air temperature and relative humidity as related to the time of the day. In the late afternoon as the sun begins to set, the temperatures decline and the humidity begins to increase.

Throughout the night the temperature continued to slowly drop, with the low of 47 °F being reached after sunrise, the next day. The highest relative humidity, 86% was achieved at this same time. As the temperature continued to warm up the next day, the humidity began to drop.

The morning drop in humidity was accompanied with the formation, within the area of observation, of heavy dew on all exposed surfaces of the earth and grasses.

The close-in clutter signals resumed the previously observed rate and level of fluctuations several hours after local sunrise. There seemed to be correlation between the radar clutter range and amplitude fluctuations with wind, and with diurnal variations in temperature and humidity.

SITE 5 (Off Prospect Area)

SITE 5 was adjacent to SITE 4, but in an area that had by helicopter/radar observation, been determined to be out of the area of radar observed gas seepage. Observations made in the daytime, showed some close-in regions to the Northwest and Southeast where fluctuations similar to those associated with the presence of seepage gases, were also observed. These observations were thus contrary to earlier helicopter observations.

SITE 6 (Off Prospect Area)

SITE 6 was similar to SITE 5, in that it was near to the active area of SITE 4, but was supposed to be out of the area of observable activity. Again there was an observation of activity, in an area, previously surveyed by the helicopter system as being free of seepage gases.

SITE 7 (Off Prospect Area)

SITE 7 was in the same general area as SITES 4, 5, and 6. It was about 2 miles south of SITE 4, in an area previously surveyed by the APS helicopter-radar, and identified as being free of seepage gases. Activity was noted, in the way of fluctuating targets that were somewhat similar to those observed at SITE 4, though the level of activity was much less than that observed at 4.

SITE 8 (Cattle Feed Lot)

SITE 8 was in northwest Texas near the New Mexico-Texas border, and was the location of an area extensive cattle feed lot. The purpose of visiting a cattle feed lot was to attempt to verify the helicopter-radar reports of very strong radar returns which were thought to be associated with both the methane and the ammonia associated with the presence of large numbers of cattle. Both the pencil and fan beam antennas were used in the observation of the cattle feed lots with the ground based radar. Use of the pencil beam did not result in any indications that radar returns were being obtained from elevated cells of gases. It was noted that the smaller pencil beam antenna, with its 2.7 ° azimuth beamwidth provided a PPI presentation which more nearly resembled the APS video-camera PPI record of cattle pens in southeast Texas. Use of the 1.2 ° azimuth beamwidth fan-beam antenna resulted in a much more detailed representation of the cattle feed lots. With that finer resolution antenna, the pipe-work grid structure of the cattle pens could be recognized, and a distinction could generally be made between those pens that did and did not contain cattle. The ground based radar observations did not result in any substantiation of the presence of elevated radar echoing cells of gas.

TABLE 1
A 24-HOUR RECORD OF TEMPERATURE AND HUMIDITY

TIME	TEMP °F	% REL HUMIDITY	WIND KNOTS	VARYING SIGNAL
1500	81	36	3	YES
2122	62	52	2	NO
2236	58	61	8	NO
0328	54	64	1	NO
0507	53	72	4	NO
0715	47	86	4	NO
0915	63	50	1	YES
1115	71	42	5	YES
1328	75	43	10	YES
1500	81	36	12	YES

SITE 9 (Various Locations)

SITE 9 represents a number of locations in northwest Texas where the mobile-lab was stopped along the roadway, and brief observations made of plowed fields, working oil fields, and a field where a new well was in the process of being drilled. The SITE 9 locations were quick, spur of the moment observations, the nature of which did not allow for setting up all equipment. Complete meteorological logs were not made, and the GPS receiver was inoperative during this mode of operation.

SITE 9 included an oil and gas field discovered in the 1950's-1960's and still actively producing. It provided some of the more interesting radar results and will be discussed later. Site 9 also included and oil and gas field only discovered in 1991. It was undergoing development (2 wells drilling) when NRL made its observations. This field though, unlike the older field, had no apparent elevated radar returns.

V. DATA ANALYSIS AND REPORTS

ELEVATED ECHOES

One of the considerations at the outset of this investigation was to determine if there was evidence to support the notion that the radar returns of interest were from elevated cells or plumes of seepage gases. The supposition was that hydrocarbon gases might, at some heights above the ground, provide radar echoes which were separable and distinct from ground clutter.

To this end the pencil beam antenna was on some occasions substituted for the fan beam antenna. The fan beam antenna with its broad vertical beamwidth (25°) did not permit the ready distinction between radar returns from the ground versus elevated targets.

Figs. 5, 6, and 7 are plots showing the vertical coverage of the two antennas used during the April 1992 investigation of seepage gases. Each plot is based on the antenna mounted at a height of 14-ft on the mobile-lab (as shown in Fig. 4). The range scale, the X-axis in each figure, is set at 3,000 ft (approximately ½ nautical mile).

Fig. 5 shows the expected vertical coverage for the fan beam antenna as it was used on the mobile-lab. It may be seen that as a consequence of the 14-ft mounting height and the 0° elevation angle, multiple elevation lobes are formed. The centers of the first three lower lobes are approximately at 0.1°, 0.3°, and 0.5°. Radar target returns observed with the vertical coverage shown in Fig. 5 could be associated with objects anywhere within the vertical coverage of from + 0.1° to 25°. The result was that when using the fan beam antenna it was not possible to distinguish between returns from surface targets and elevated targets. Discrete ground targets as well as airborne targets were observed with the subject antenna. The determination of which targets were elevated or on the surface could not be deduced from the radar display alone. The only elevated targets noted with this antenna were birds (turkey vultures and hawks) for which there were positive visual identifications.

Fig. 6 shows the expected vertical coverage for the NRL pencil beam antenna, when that antenna is horizontal, with its beam center pointed at the local horizon. As with the fan beam antenna, an elevation lobing structure is created. With the beam center directed at the horizon, except for nulls in the coverage, radar target returns could be associated with objects anywhere from 0.1° to about 2.0°.

In Fig. 7, the elevation angle of the beam center has been changed from the 0° angle shown in Fig. 6, to a + 3°. As a result, the vertical lobing structure near the horizon is practically eliminated. Radar target returns observed with this vertical coverage, can be reasonably assessed as being within the 3-db beamwidth of the elevated vertical beam.

During the course of observations at the several sites visited, the pencil beam antenna was exercised with observations being made with elevation angles of 0°. + 3°, + 6°, and +10°. The only elevated targets noted with the pencil beam antenna were birds (vultures and hawks). Other radar returns from what might have been associated with seepage gases an/or convective cell activity were not observed with the elevated pencil beam.

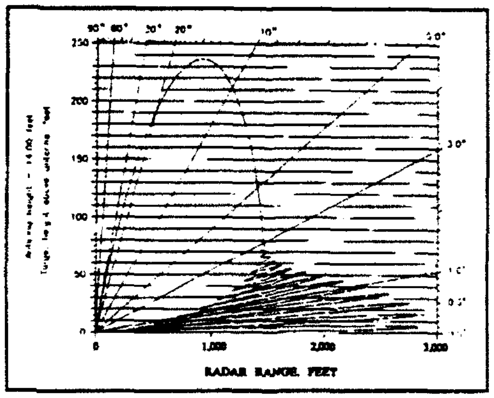

Fig. 5 R-82 fan beam antenna elevation coverage for a 14-ft mounting height and 0° elevation.

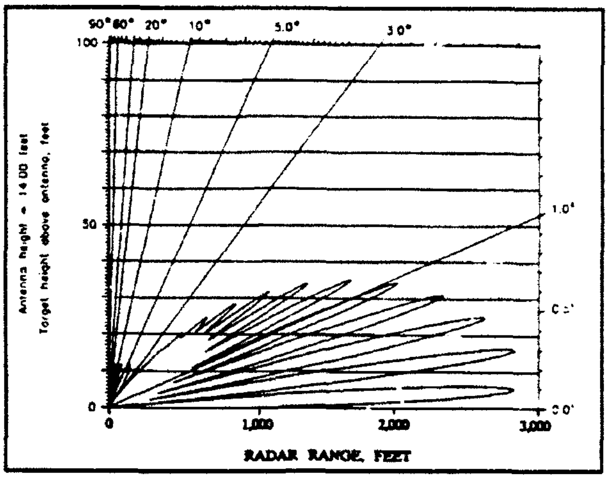

Fig. 6 NRL pencil beam antenna elevation coverage for a 14-ft mounting height, and a 0° elevation.

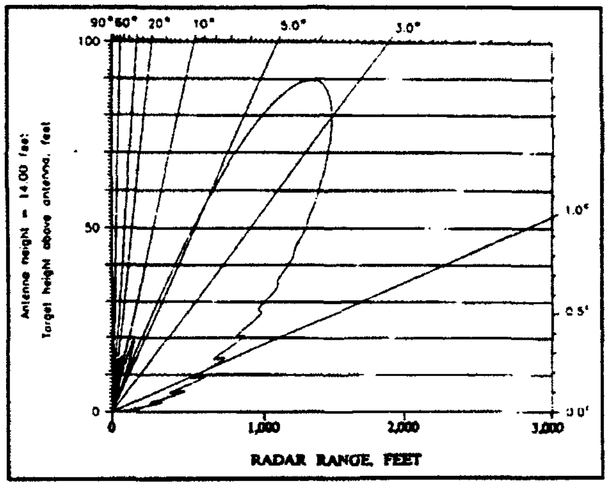

Fig. 7 NRL pencil beam antenna vertical coverage for a 14-ft mounting height and a + 3° elevation angle.

From Fig. 7 it may be developed that with the pencil beam set for a + 3° elevation angle, at a range of 500 ft targets would have to be between 24 and 74 ft in height to be within the 1st elevation lobe. The indications are then, that an elevated target observed with the fan beam of Fig. 6, and not observed with the pencil beam at elevation angles of + 3° or more, is then at a height that subtends less than a + 1° elevation angle (approximately 24 ft at a range of 500 ft). Except for the previously mentioned birds, radar returns were not observed when the pencil beam was adjusted to observe at positive antenna elevation angles of 3°, 6°, and 10°.

POTENTIAL SEEPAGE GAS RADAR RETURNS

The adjective potential is used when discussing these returns, as the expected instrumentation for determining the presence, constituency, and concentration of hydrocarbon gases that may have been in the radar "field of view," suffered mechanical breakdown problems, and never arrived at the investigation sites. However, we believe these echoes are unique and are not associated with normal clutter.

Fig. 8 below is a rising raster display for data acquired at SITE 4 on April 05, 1992. The rising raster display is a succession of A-scope traces, similar to those indicated in Fig. 1, where after each trace is completed, the baseline is displaced vertically. In this presentation it is possible in a single view to convey the time-history of signal returns for the radar in a manner which allows for the viewer to more readily detect changes in signal amplitude or in range.

In Fig. 8, range in feet is depicted along the X-axis (abscissa). The numbers on the Y-axis (ordinate scale) are representative of data recorder time. The radar transmitter for this data was operating at a pulse repetition rate of 1,000 pulses per second. For the display in Fig. 8 only every 10th pulse return is displayed. The total elapsed time from the first to the last trace in the figure is then 1-second.

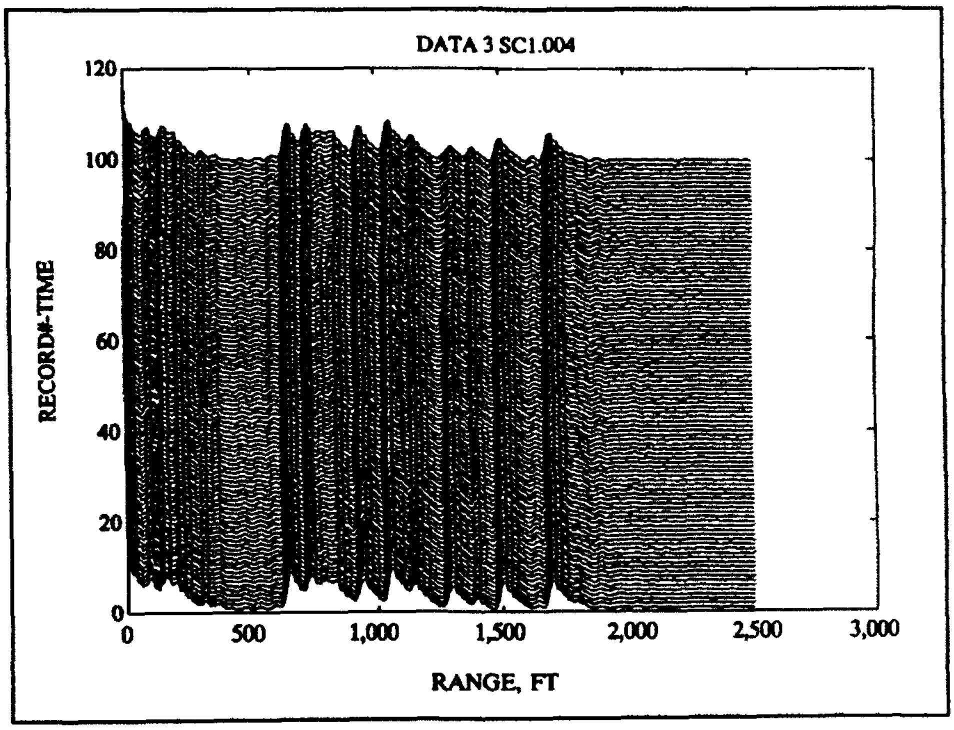

Fig. 8 Rising raster A-scope display for SITE 4, showing stable, fixed target radar returns at 110° azimuth (fan beam antenna).

Note, the perception of changes in signal amplitude and range for a display like that of Fig. 8, may be more readily accomplished through the technique of tilting the page so that the top-to-bottom aspect of the figure is viewed at an oblique angle.

The data in Fig. 8 is from the fan beam antenna, stopped and radiating along a bearing of 110° (DATA 3 SC1.004, 110°, APR 5, 1992, 11:51 AM). The radar is at SITE 4, a location where fluctuating returns were observed with both the ground-based and the helicopter-borne radar. The particular antenna bearing represented is for a direction and range in which there were not any significant varying, potentially seepage gas related, radar returns. The returns are quite stable, showing very little amplitude or range variation. In short, this is the type of record that would be associated with scattering from small fixed targets. The likelihood is that those peaks in signal that may be observed for ranges of 600 to 1,700 ft are associated with scattering from yucca plants noted for this particular location.

In Fig. 9, the conditions are that the radar is at the same SITE 4 location as in Fig. 8. The significant operating difference between Fig. 8 and Fig. 9, is that the antenna has been positioned to radiate along a bearing of 223° (DATA 3 SC1.002, 223°, 11:43 AM, APR 5,1992). This was an area in which significant signals were observed by the helicopter and ground radars on April 5, and by the ground radar on the 7th, 8th, and 9th of April.

Several features should be noted about the display in Fig. 9. First there are relatively stable signals to be observed in Fig. 9. Note a weak but stable signal at 500-ft. Other stable signals are to be noted at 750, 1,350, 1,550, and 2,350 ft.

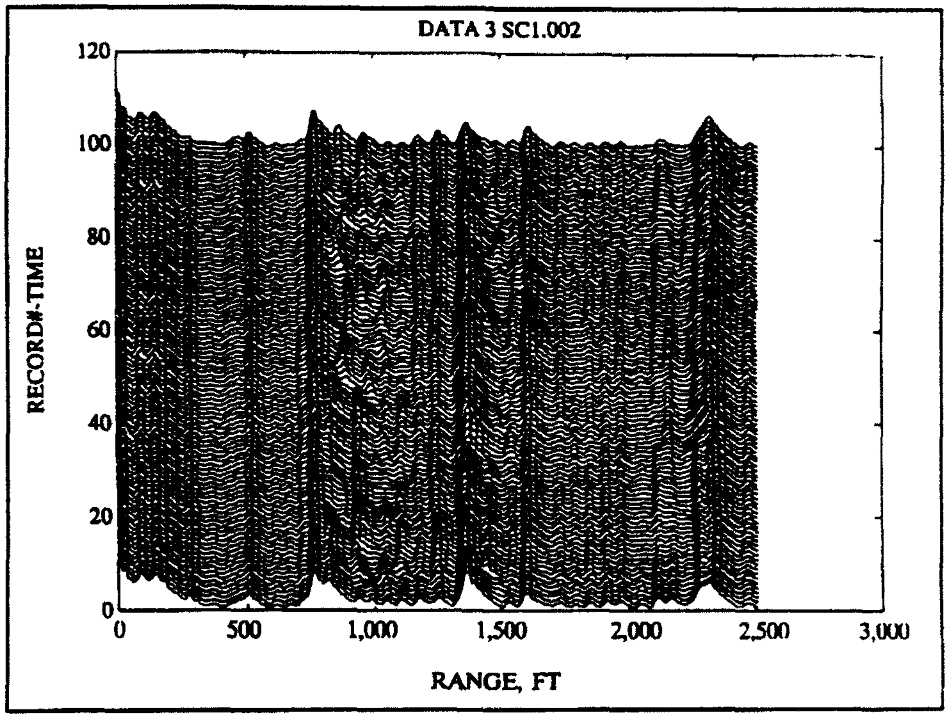

Fig. 9 Rising raster, A-scope display for SITE 4, showing both fixed and variable radar target returns for the 223° line of bearing.

In Fig. 9, note the two large and stable returns at ranges of 750 and 1350 feet. These two large returns bound a region in which there are a number of low level variable return echo signals. Note, that the two fixed targets, probably yucca plants, show stable range and amplitude values.

Fig. 10 is a section of Fig. 9, enlarged to allow for examination of one of the range and amplitude varying sets of radar return signals.

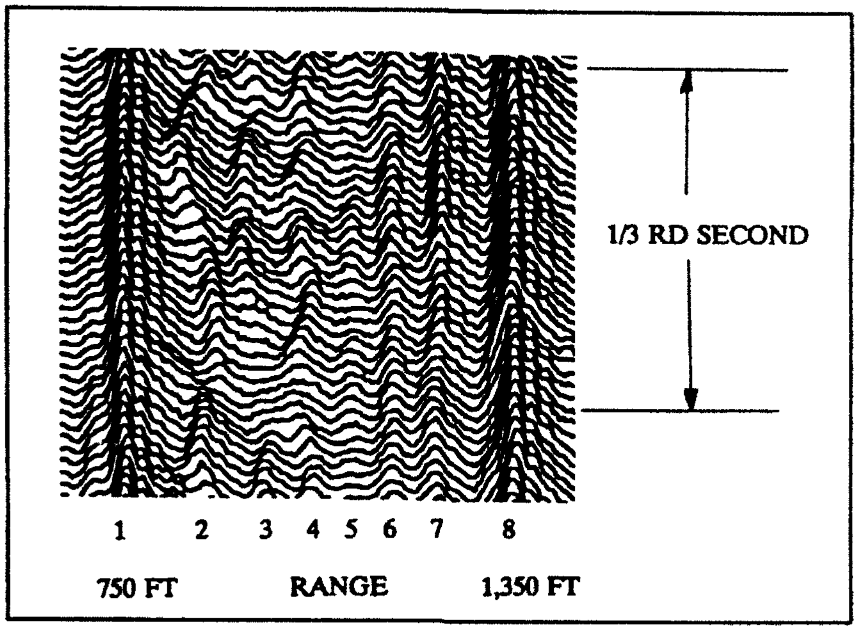

Fig. 10 Rising raster A-scope display showing multiple amplitude and range varying radar returns for SITE 4.

Examination of this figure reveals that there are 8 sets of recognizable signals. The signals in Fig. 10 are numbered from left to right. The fixed signals are those at the pulse positions numbered as 1, 5, 6, 7, and 8. The two largest signals, those at positions 1 and 8 are the probable yucca plants referred to in the discussion of Fig. 9. The signals at pulse positions 5, 6, and 7 are echoes from other, weaker targets, which exhibit characteristics of a relatively stable amplitude and a constant range.

Signal traces 2, 3, and 4 are examples of signals observed at SITE 4 that evidenced detectable variations in range and in amplitude as a function of time.

Consider the first of the range and amplitude varying returns, the 1/3rd second record indicated for the signal at pulse position 2. The signal amplitude passes through a 0 to +10 dB signal-to-noise variation, with the 10 dB level being reached at a range of 860 ft. The total range excursion for that particular target (or part of a distributed target) within the 1/3rd second interval is about ± 60 ft.

The velocity indicated by a range change of 60-ft in 1/3 second is equal to about 55 meters/second (106 knots). It is not likely that the echo is not moving with that speed, rather that the radar phenomena of target glint is being encountered. Radar glint is defined as: *the random component of target location error caused by variations in the phase front of the target signal (as contrasted with scintillation error). Glint may affect angle, range or Doppler measurements, and may have peak values corresponding to locations beyond the true target extent in the measured coordinate.*[6] Glint occurs when there is more than one scattering object within the radar resolution cell.

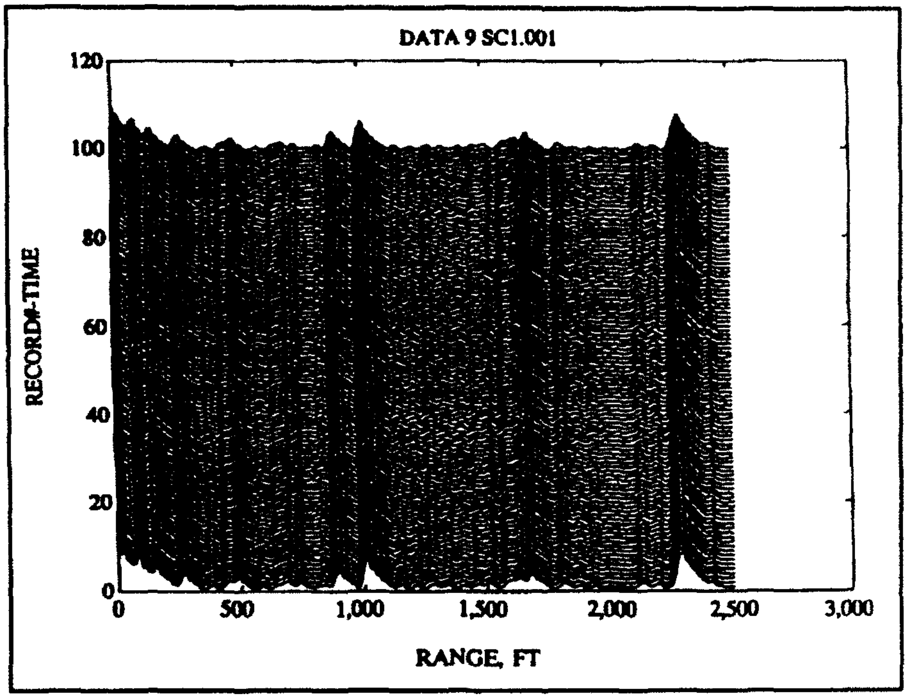

Fig. 11 A rising raster A-scope record for SITE 4 at night time, 224° bearing.

Fig. 11 is another rising raster A-scope display for SITE 4. This display is for comparison with the record shown in Fig. 9. The purpose of the comparison is to indicate the lack of variable amplitude and range returns for local night time conditions as compared with local day time conditions. The data set for Fig. 11 is identified as DATA 9 SC1.001. The data was acquired on April 08, 1992 at 3:31 AM with the fan beam antenna on a bearing of 224°. The azimuth for the two displays (Fig. 9 and Fig. 11) is approximately, though not exactly the same. (The approximate relationship between the two azimuths is due to the sharpness of the antenna azimuth pattern and the lack of a precision azimuth measurements capability.) The point to be noted is that at SITE 4, in the day time, the time/amplitude/range varying return signals of interest could be observed over an extensive region from lines of bearing from 180° to about 270°. At night-time, regardless of the bearing, signal levels were in general, of lower level than was observed in the daytime, and the variable signals were not detected.

Figs. 8 through 11 are examples signals observed at SITE 4, over 4 day period of observation. For daytime observations there was a generally consistent pattern in that amplitude and range varying signals were observed on each of the 4 days, along the a sector centered around a bearing of 224°. At the same time, a sector along a bearing of 110° was always absent the varying signals. Only one night of observation was attempted at SITE 4, and results from that period are shown in Fig. 11. The daytime varying signals disappeared at night time. Signals from that same sector around the 224° bearing re-appeared the following morning. Observation of other parameters (Appendix A) suggests that some of the radar signals may be exhibiting a diurnal variation where solar heating, ambient humidity, and local winds may be moderators of the presence and level of the variable radar returns.

Fig. 12 is an example of the more dynamic variable radar returns observed in the vicinity of producing oil fields. For the example shown, the mobile-lab ground-based radar was pulled off onto the shoulder of a road in northeast New Mexico, and observations were made with the fan beam antenna looking towards but not directly at working oil jack pumps. This field dates from the 1950's-1960's and is still actively producing. The data set for Fig. 12 is identified as DATA 15 SC1.005, April 10, 1992, acquired at 3:27 PM with the fan beam antenna.

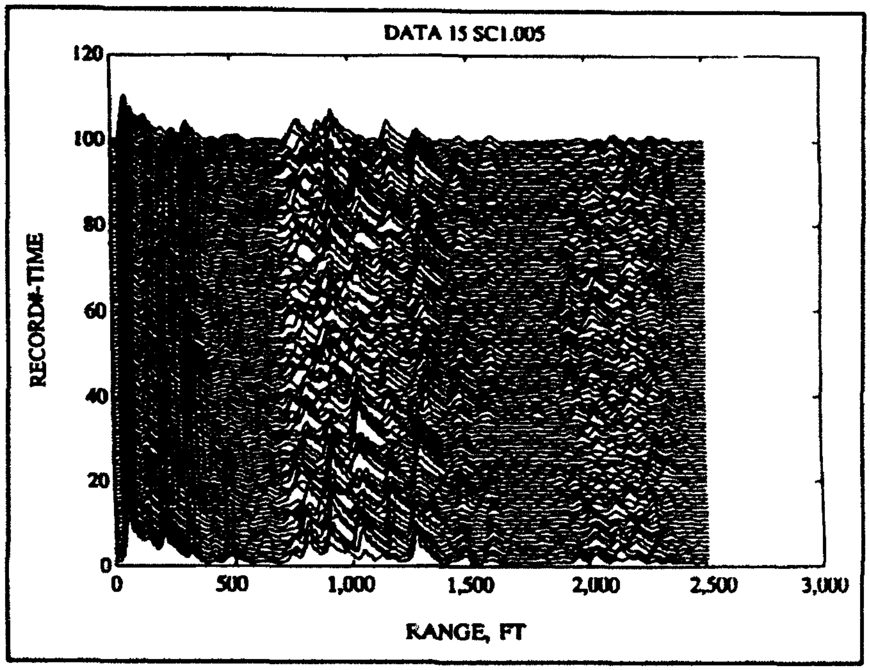

Fig. 12 Rising raster A-scope for a producing oil field in Northwest Texas.

As an example of the amplitude variation in Fig. 12, note the amplitude of the signal at a range of 1,280 ft. That signal, for the first or bottom trace, is at an approximate 16 dB signal-to-noise (SNR) level. Tracing that signal upwards, it may be seen that at about RECORD#-TIME 14 through 35 (about 0.15 to 0.35 seconds from the start of the record), the signal had decreased to the noise level. The subject signal fades in an out several times during the course of the total record. Further, the record at times shows both gradual and abrupt range changes which vary from 1,250 to 1,300 ft.

The small pulse at a range of 1,580 ft, on the first or bottom trace in Fig. 12, is similar to the range and amplitude varying signals noted at SITE 4. The SNR for the first several traces of this record is about 7 dB. That signal level drops to the noise level after approximately 0.2 seconds.

At this time the seemingly chaotic signals between the ranges of 750 to 1,200 ft are not understood, and they may or may not be associated with the presence of gases which may have been within the radar field of view.

Records similar to that shown in Fig. 12 were obtained at two different locations in the northwest

Texas and eastern New Mexico. All of these later records were short observations of opportunity, made without the benefit of maps and previous survey data that had been available at SITE 1 through 8. The impression gained was that the variable signals were more intense than those observed at SITE 4.

Fig. 13 is generated through solution of the radar equation as developed in Appendix C. The initial reference was to an 8-inch diameter metal sphere target (RCS = 0.0324 sq. meters), which at a range of 350-ft resulted in an approximate 20 dB SNR for the lowest of the antenna elevation lobes.

Approximations of radar cross sections for the preceding falling-raster records may be arrived at through reference to Fig. 13. As an example of radar cross sections, consider the return at 550 ft range shown in Fig. 12 (producing oil field records). That signal, in the first or bottom trace exhibits an approximate 6 dB SNR. That SNR for a range of 550 ft, indicates a target radar cross section on the order of 0.01 square meters.

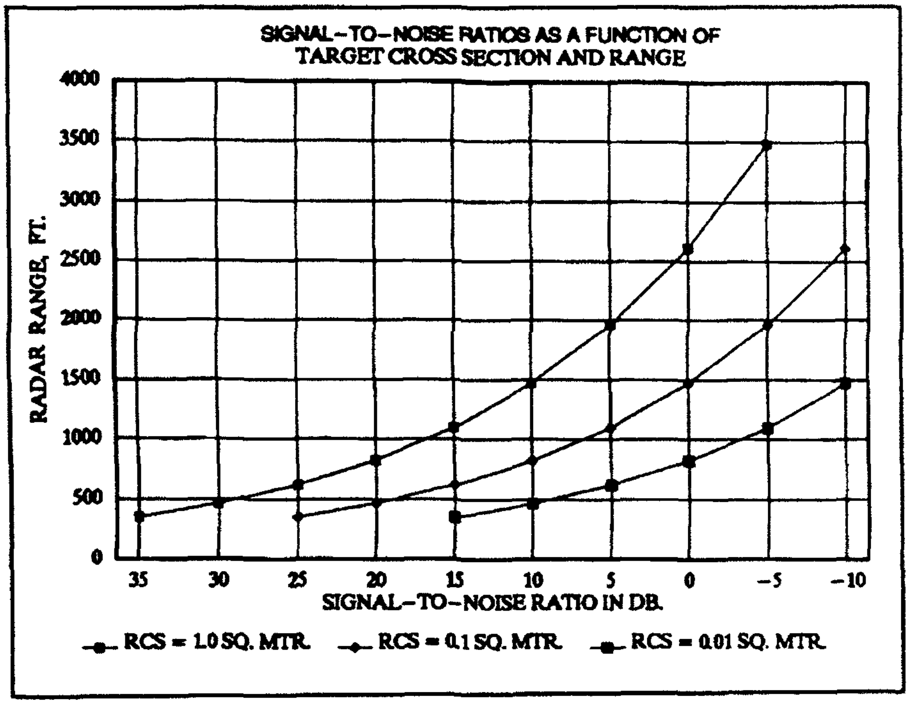

Fig. 13 Signal-to-noise ratios as a function of target cross section and range.

A second example from Fig. 12 is the target at 1,250-1,300 range that appears on the first or bottom trace of the record. That target has an approximate 16 dB SNR, which suggests a target radar cross section on the order of 2.1 square meters.

A third example from Fig. 12, is the 7 dB signal at 1,580 ft, for which the indicated radar cross section is about 0.7 square meters.

The radar cross sections associated with the variable signals at SITE 4, are 0.12 square meters for the

signal for the 10 dB SNR at 860 ft (pulse position 2 in Fig. 10), and 0.17 square meters for the at 8 dB SNR at 1,050 ft (pulse position 5 in Fig.10).

The signal at 750 ft range in Fig. 9, judged to be the return from a probable yucca plant had a cross section of 0.7 square meters.

TABLE II
RADAR CROSS SECTION

SITE	RANGE, FT	SNR, dB	RCS, M^2	CELL VOLUME, M^3	COEFFICIENT
9	550	6	0.01	125	8×10^{-5}
4	750	20	0.7	NA	NA
4	860	10	0.12	230	3×10^{-3}
4	1.050	8	0.17	450	3.8×10^{-4}
9	1.280	16	2.1	670	3.1×10^{-3}
9	1.580	7	0.7	1.020	6.9×10^{-4}

The values entered in the coefficient column above are radar backscatter coefficients. The backscatter coefficient is a measure of the ability of a distributed radar target, such as a gas, to reflect energy to a radar receiving antenna.

As noted earlier, pencil beam observations suggested that the unique variable returns, we believe associated with gas seepage occurred at elevation angles of less that three degrees. For analysis, an assumption is made that the observed returns were from volumes of space that did not extend above a 1° elevation angle. The dimension of a radar resolution element for a range of 550 ft (167.7 meters) is then :

height = 2.97 m
width = 3.5 m
depth = 12 m
volume = 125 m^3

The computed radar cross section for the distributed target at 550 ft was determined to be 0.01 square meters. The radar resolution element volume at that range was determined to be 125 cubic meters. The backscatter coefficient, σ_0, is then:

$$\sigma_0 = 0.01 / 125$$

$$= 8 \times 10^{-5}$$

The **not applicable** (NA) note for the 2nd set of data in the above table, is for the reason that the entry is for a stable (probable yucca plant) target and not a turbulent seepage gas scattering volume. Except for the presumed yucca plant, all of the values for the backscattter coefficient in Table II are regarded as high compared to the coefficient expected from a gaseous turbulent medium.

The differences between measured and expected values of target radar cross sections and backscatter coefficients may be attributed to the following: the radar system was not calibrated until weeks after the

acquisition of data in Texas; the modeling of antenna vertical lobes and the dimensions of radar resolution cells is subject to error; surface reflectivity and the impact of actual terrain roughness was not measured; and possibly most important, the adjustment of radar system sensitivity was accomplished with an uncalibrated potentiometer, always leaving an uncertainty as to what the exact system sensitivity was at any given time. The field estimation of system sensitivity alone, may have introduced as much as 5 dB error in SNR determinations.

WEATHER

Anecdotal references relative to the use of radars for seepage gas exploration make reference to the impact of rain on the detectability of the signals of interest.

During the course of the April 5, 1992 observations at SITE 4, data was acquired prior to, and after an intense rain storm. Prior to the passage of the storm over the ground test site, both the helicopter radar and the ground-based radar acquired what appeared to be comparable PPI data. Possible seepage gas radar returns were being obtained within a 1/2 nm radius along sectors which ran to the southwest and northeast of the ground based site.

An intense electrical, hail, and rainstorm passed over the ground based site on the afternoon of April 5, 1992. The nature of the storm was such, that for the safety of personnel and equipment, power was turned off and no data acquired for approximately 30 minutes before and after the passage of the storm over the site. Prior to shutting the system down, signal returns such as those of which Fig. 9 is an example, had been under continuous observation for three hours.

Within about 30 minutes after the storm had passed over the site, the radar was turned on. The initial observations after the storm impressed the several observers, in that the A-scope display was devoid of any varying signals. Over the next approximately 10-minute period, as the several observers watched the display, the variable signal began to reappear and build in level. These observations seem to agree with the anecdotal records for observations by others to the effect that rain and wet ground act to diminish the radar return associated with the presence of seepage gases.

A possible accounting for the differences in the radar observations at SITE 1 and SITE 4 after a rain are: at SITE 1, the ground had been thoroughly saturated with water prior to commencing observations and remained in that condition; at SITE 4, the ground had been hard and dry prior to the storm and afterwards most of the rainfall ran off rapidly without penetrating beyond an estimated 1/2 inch.

DETECTION OF GASES FROM CATTLE

A radar video record made several months previously by the APS helicopter-radar group suggested that the radar and technique employed by them for seepage gas exploration was also capable of detecting hydrocarbons gases produced by cattle. Cattle digestive processes are known to generate significant quantities of methane, and their urine is a source of ammonia. As an additional check on overall performance, the NRL April 1992 radar investigation included a visit to a large cattle feed lot in northwest Texas. The results of the cattle feed lot investigation are negative in that radar return signals with variations in amplitude and range similar to those associated with both a producing oil field a potential oil and gas bearing field were not observed.

VI. DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

Signal Characteristics

Unique radar signals which we believe are associated with gas seepage were observed during the course of the NRL radar observations in Texas during April 1992. Important to the consideration of uniqueness relative to the presence of petroleum products are the following findings:

Radar measurements within an established oil field resulted in the detection of a particular pattern of return signals which were characterized by fluctuations in range and amplitude that differed from those associated with normal clutter.

Radar observations of a potential oil and gas bearing field resulted in the detection of variable signals which were similar to those noted for a producing field.

The return signals emanated within localized regions where there were no visually identifiable hard targets (man-made or natural such as bushes and trees).

The subject signals were unique in that they exhibited the following characteristics:

A. The signals of interest varied in amplitude from the noise threshold, 0 dB, to more than 10 dB over time intervals of less than one-third of a second. (page 16)

B. The fluctuating echoes exhibited range changes of ± 60 ft. (page 16)

C. They exhibited radar cross sections on the order of 0.01 to 2.1 square meters. (page 20)

D. On one occasion the unique fluctuating signals diminished and then disappeared with the onset of local hours of darkness. Several hours after sunrise, the signals reappeared. The cause is unknown. (page 17)

E. Rain and/or wet ground resulted in a suspension of observable variable signal activity. (pages 7 and 9)

F. The observational evidence is that the observed signals returns where for targets at heights no higher than 25 ft. (page 13)

Seepage Gas Association

The signals of interest observed during the subject investigation can not be identified with any certainty as being radar returns from seepage gases. Two general classes of measurements were needed, neither of which could be carried out for reasons of equipment failure and funding limits. The two types of measurements were (1) 'in situ' measurement of the presence, type, and concentration of hydrocarbon gases; and (2) measurement of the turbulent structure function constant for the gaseous volumes illuminated by the radar. The latter is probably more important than the former.

The association of the ground based radar returns of interest with seepage gases can be inferred through reference to the characteristics of the observed signal return, through reference to the findings of the airborne radar seepage gas explorations, and the existing environmental conditions. The likelihood that radar returns from SITE 9 are associated with seepage gases is higher than that for SITE 4, as SITE 9 included producing oil wells, while SITE 4 was virgin territory without producing wells to demonstrate the presence of gas or oil.

CAVEATS

It had been hoped that this investigation might yield simple, clear-cut results. Yet at the outset, a cautionary note was sounded to the effect that the planned investigation might not fulfill all of what was desired.

It was pointed out during sevral planning meetings that a clear-cut correlation of radar returns with the documented presence of known quantities of hydrocarbon gases would still be accompanied by:

A. A minuscule data base (data acquired over a 10 day period, for 2-3 sites).

B. A data base without any meaningful inclusion of diurnal, seasonal, or geographic variability.

C. A level of effort, for which a meaningful, in-depth analysis of data could not be accomplished within the time and funding resources available. The analysis promised was that of a limited "skimming the cream off the top," to provide a first order indication of the radar signal characteristics.

CONCLUSIONS

Unique radar returns were observed. The nature of the radar returns was such that it is possible that they are associated with the presence of petroleum related seepage gases.

The unique character of the radar returns is to be found in the pattern of variability in both signal amplitude and range. The signals evidenced range changes of ± 60 ft and amplitude variations of from 0 to more than 10 dB in time intervals of a fraction of a second. Radar cross sections associated with the signals were on the order of 0.01 to 2.1 square meters, over ranges of from 550 to 1,580 ft.

Signal uniqueness is also indicated through the observation that the returns did not correlate with any distinctive terrain features. They were not associated with natural ground clutter - rocks, earthen depressions or prominences, or with man-made objects.

The ground based radar showed that it may well be a useful tool in the search for seepage gases. The ground based system offered several significant advantages over present APS airborne system. One, it is capable of detecting both the range, amplitude, or spatial variations of the return signals. The airborne system as configured through April 1992 was used to sense broad area radar amplitude variations, and could not be used to sense the range variations observed with the ground based radar. Two, the ground system allowed for the rapid employment of, and evaluation of returns through the use of both a fan and pencil beam antenna. Three, the ground system was capable of superior recording, processing, and display of the radar data.

Anecdotal references by previous investigators as to the suppression of seepage gas related radar returns as a result of rain were confirmed.

The ground based radar showed that it may well be a useful tool in the search for seepage gases. The ground based system offered several significant advantages over present APS airborne system. One, it is capable of detecting both the range, amplitude, or spatial variations of the return signals. The airborne system as configured through April 1992 was used to sense broad area radar amplitude variations, and could not be used to sense the range variations observed with the ground based radar. Two, the ground system allowed for the rapid employment of, and evaluation of returns through the use of both a fan and pencil beam antenna. Three, the ground system was capable of superior recording, processing, and display of the radar data.

Anecdotal references by previous investigators as to the suppression of seepage gas related radar returns as a result of rain were confirmed.

Radar pencil beam antenna elevation angle "cuts" indicated that the radar returns of interest were not detectable with antenna beam elevations of + 3° or more. Based on the fan beam antenna observation of a variable target at a range of 550 ft, the results suggest that if the variable target returns are from gases, those gases constituting the echoing volume were at an altitude of 25 ft or less.

RECOMMENDATIONS

Additional observations should be made, concentrating on measurements and characterization of radar returns for a known oil producing field.

Data be acquired at a single site for a minimum of 10 days. Data acquisition should include sampling over several 24-hour periods, so as to address the concern for diurnal variations.

Simultaneously with the acquisition of radar data, 'in situ' measurements be made to document the turbulent structure function constant and determine the types and levels of concentration of gases within the radar's resolution cell when the characteristic fluctuating echoes are observed.

VII. REFERENCES

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2. M. Skolnik, "Radar Detection of Hydrocarbon Gas Seepage Associated with Underground Oil and Gas Deposits," NRL Memorandum Report 6245, July 12, 1988.

3. Cooperative Research and Development Agreement Between Naval Research Laboratory and AMOCO Production Company, 21 page document signed December 9, 1991.

4. M. Skolnik, D. Hemenway, and J. Hansen, "Radar Detection of Gas Seepage Assocoated with Oil and Gas Deposits" IEEE Transactions on Geoscience and Remote Sensing" Vol 30, No. 3, May 1992.

5. D. L. Grayson and D. K. Killinger, "Rapid Calculation Techniques for Radar Performance Prediction," Naval Avionics Facility report TR-155-4, 17 April 1970.

6. IEEE Standard Dictionary of Electrical & Electronics Terms, Second Edition, IEEE Std 100-1977 John Wiley & Sons.

VIII. ACRONYMS AND ABBREVIATIONS

APS	Airborne Petroleum Surveys, Inc
CRDA	Cooperative Research and Development Agreement
dB	decibel
FTIR	Fourier Transform Infra Red
GPS	global positioning system
Hz	Hertz (cycles per second)
mph	miles per hour
nmi	nautical mile (6,076 ft)
NRL	Naval Research Laboratory
PPI	plan position indicator
SNR	signal-to-noise ratio

APPENDIX A
SITE DESCRIPTIONS AND NARATIVES

The following is a more detailed description of each of the major sites visited during the course of the 2-weeks investigation of the microwave sensing of seepage gases. The seepage gases of interest have been presumed to be hydrocarbon gases, which might be associated with the presence of underground deposits of petroleum gases and oil. The exact location of each site is not revealed in this report. as such information is proprietary to **AMOCO**.

As may be appropriate and dependent on the data available, each of the major sites visited will be documented according to the following format: A - general location, B - maps, C - photographs, D - dates of investigation, E - general description, and F - weather.

As may be appreciated by reference to the narrative accounting of activities at each site, some of the sites were judged to be unsuitable for further observations. The reasons for such a determination are given in the narrative account.

SITE 1

GENERAL LOCATION - **Site 1** is in east Texas on a producing field.

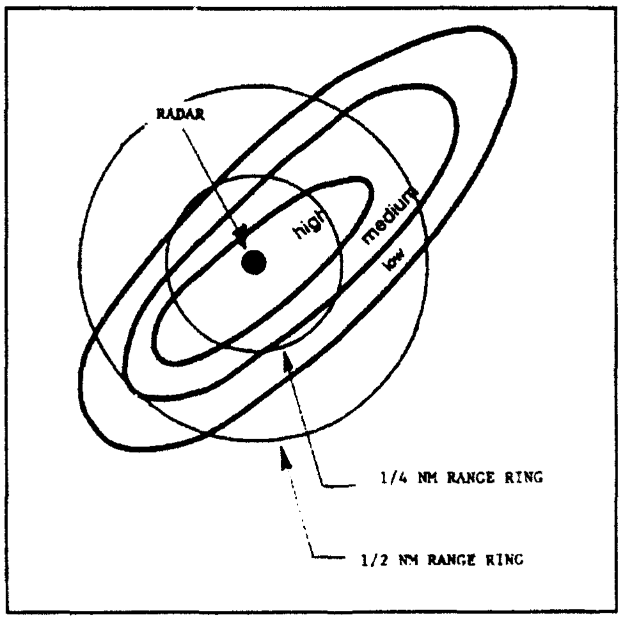

Fig. A-1 Location of the ground-based radar relative to the helicopter radar-map of seepage gas.

In Fig. A-1 the three contour lines represent relative levels of radar video intensity as determined by previous helicopter radar surveys by APS. The inner contour identifies a high level of radar return or a high level of seepage gas. The next contour represents a medium level of seepage gas. The third contour shows the limit for the minimum radar detectable levels of seepage gases. Beyond the last contour, gas associated radar returns were not observed.

The scale in Fig. A-1 is only approximate, The distance from the ground-based radar to the gas well-head was 600-ft.

Figs. A-2 and A-3 are photographs which indicate the type of terrain, and the location of the radar relative to terrain features. In Fig. A-2, an aerial view, it may be seen that the radar (on the mobile-lab platform) is located in a grassy field. Trees and a road bound the three sides of the field.

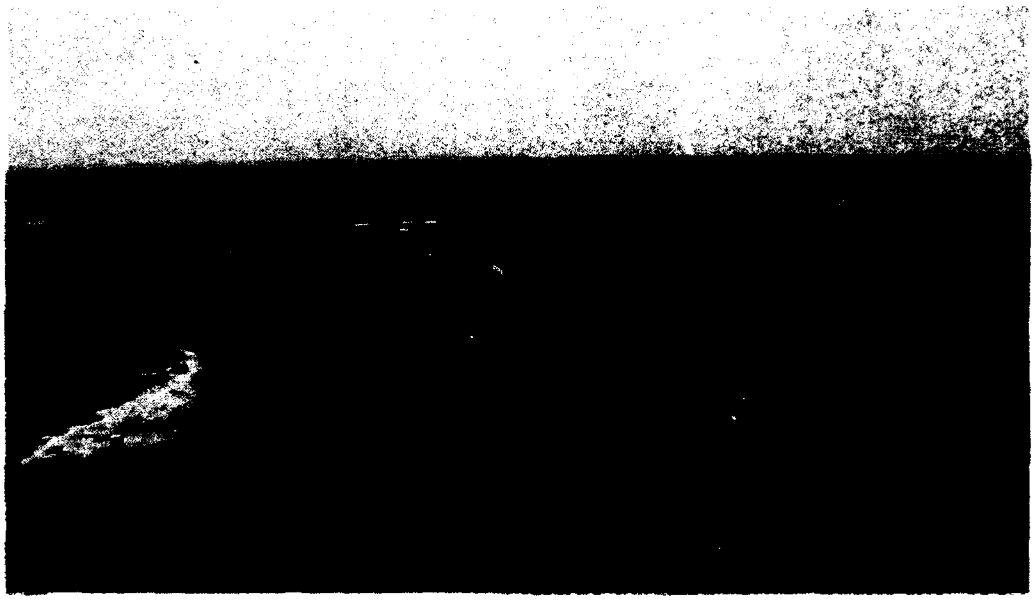

Fig. A-2 East Texas **SITE 1**. The ground-based radar is in the upper center. The gas well-head is in the left-center.

Fig. A-3 The same field as shown in Fig. A-2, as viewed from the antenna of the ground-based radar system. Storage tank and wellhead in upper center.

An important feature of the photograph in Fig. A-3 is that is shows distinct areas of predominately long grasses in the foreground, and then short grass in the middle ground.

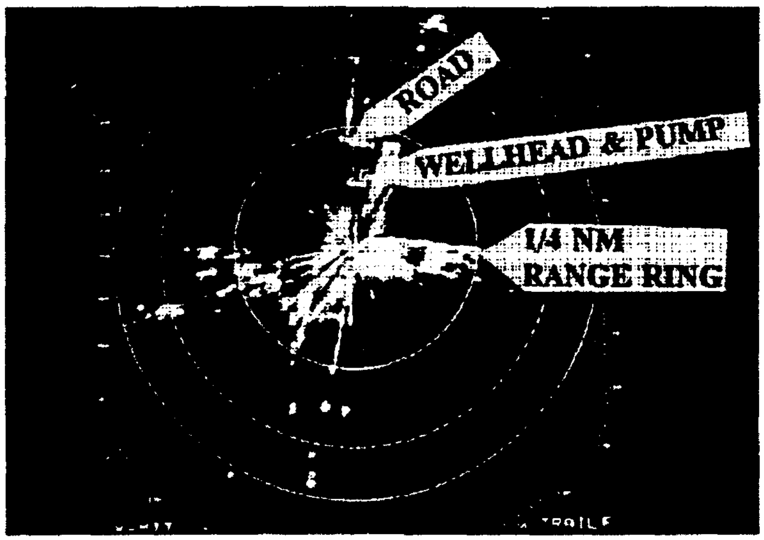

Fig. A-4 A photograph of a PPI display for **SITE 1**.

Fig. A-4 is a photographic record of a PPI display for **SITE 1**. There is a considerable loss in detail in photo copies as that shown above. Specific identification is indicated in the photo for the location of the road to the east of the radar position, and of the location of the well-head and associated storage tank and pump.

The NRL ground-based radar and associated monitoring and recording equipment was installed in the mobile-lab vehicle shown in Fig. A-5. As shown in the photograph, the antenna was at a height of 14-ft above ground. In the photograph, the 60ft scanning array antenna was mounted on the receiver-transmitter module, the white cubical structure immediately on top of the tripod mount. The 32-inch diameter dish antenna, used for elevation scans is shown in a storage position, between the tripod and the mast. The mast at the rear of the vehicle supports the meteorological station sensors and the antenna for the Global Positioning System (GPS) receiver.

Fig. A-5 shows a typical fixed station configuration for the ground-based radar system. In the latter part of the investigation, the system was operated "in motion. For that configuration the GPS/meteorological mast was lowered, the tripod was removed, and the array antenna and pedestal were mounted directly to the top of the mobile-lab, with a resulting antenna height of 12-ft above the local ground surface.

Fig. A-5 The NRL equipment vehicle (a mobile-lab), shown on location at SITE 1 in east Texas.

DATES OF OPERATION

The ground-based radar arrived at SITE 1, at about 0900, local time, on Monday, March 29, 1992. Initial radar operations were started at about 1100 hours.

Operations continued through until about 1800 on Tuesday, March 30, 1992. From about 1100 to 1500 on Tuesday, joint operations were conducted with the ground-based radar and the helicopter-borne radar.

The ground at SITE 1 was wet and soft from earlier rains. A prediction of further heavy rains for Tuesday night, raised the risk that the radar vehicle could become mired and unable to move without outside assistance. That condition, coupled with the APS radar determination that seepage gases were not being detected in the immediate vicinity, led to a decision to cease operations. The mobile-lab was moved to near-by hard ground and preparations were made to move to southwest Texas the next day.

SITE DESCRIPTION

SITE 1 was on relatively flat terrain in east Texas. The ground-based radar was set-up in an open field, see Fig. A-2. The field was approximatley rectangular with trees bounding three sides, with a road on the 4th side. The field was the site of a producing gas well. The well-head and associated storage/equipment shelters are visible in the aerial photograph of Fig. A-2.

The distance from the ground-based radar system antenna to the well-head was 600 ft. Three corner reflectors were set out along a radial, approximately 30° to the left of the line of bearing from the radar to the well-head. The reflectors were positioned at ranges of 400, 600, and 800 ft from the radar. They were mounted atop 18-ft wooden masts.

In the center of the photograph, A-2, a somewhat rectangular , darkened area may be made out in the center of the field. The darkened area defines a region of short grass, wet ground, and a depression. That area showed up as a dark region (meaning there was little or no backscatter) on the PPI display.

WEATHER

TABLE A-1
MARCH 30, 1992 WEATHER DATA

TIME	TEMP °F	% RH	PRESS. IN-HG	WIND DIR °	WIND KNOT S	NOTES
0930	55	68	29.99	45	8-10	OVERCAST
1200	62.5	67	29.95	45	5-7	50% CLOUDS
1400	67	58	29.93	45	6-9	10% CLOUDS
1700	64	74	29.91	45	3-5	CLEAR

TABLE A-2
MARCH 31, 1992 WEATHER DATA

TIME	TEMP °F	% RH	PRESS. IN-HG	WIND DIR °	WIND KNOTS	NOTES
0755	51	84	29.82	90	5-6	HAZE
0850	54	75	29.81	45	6-7	CLEAR
0950	60		29.91	120	2-3	CLEAR
1010	73		29.91	0	0	CLEAR

Weather during the two days of operation changed from overcast to sunny, clear and mild. Local weather predictions of severe storms for that area of Texas on the evening of March 31, 1992, contributed to the decision to cease operations. By the time the radar and associated equipment had been stowed for transport, the local weather scene had changed from clear and sunny to an overcast and the start of light showers.

NARRATIVE

The ground-based radar was set-up at SITE 1 on the morning of March 30, 1992. After the initial system check on radar operation, general observation and documentation of the radar returns for the local area were started. Initially the 6-ft array antenna was used to obtain a series of PPI records of the local area. Most observations were made with a maximum display range of 0.5 nm, the same display range use by the APS radar operator/observer.

After acquiring data with the array antenna, the radar output was switched to the pencil beam antenna. Observations at **SITE 1** with the pencil beam did not result in the observation of radar returns from elevated heights. One type of elevated return was observed, the return from single and multiple birds. Some birds were tracked at ranges of greater than 2 nm. At shorter ranges, positive identification was made that most of the visually correlated bird targets were turkey buzzards and a few large hawks.

The ground-based radar observers were not versed in the APS operating technique for microwave detection of seepage gases. They had however, all viewed the earlier APS promotional video recording. The general characteristics which were sought, were for a broad area of returns, detectable at ranges of 700 to 2,000 ft. The impression gained from the PPI video camera records of the helicopter radar was that the echoing

area was difuse and changing from one antenna scan to the next.

The ground-based system operators, in searching for candidate returns, settled on three areas which provided what they thought were returns with characteristics similar to those viewed in earlier APS video camera records. The subject returns were at ranges of 0.4 to 1.0 nm, and at relative bearings of about 20°, 170°, and 230°.

On the second day at SITE 1, when the APS helicopter arrived in the area, it was vectored to and over the locations of the three candidate positions. The in-flight reports were "We are over a copse of trees." Then "we are over another copse of trees," and then "we are now over a house and some trees." The locations picked out by the untrained observers did not correlate with the helicopter observed regions of microwave detected seepage activity for that particular day and time.

The helicopter-borne radar did re-survey the SITE 1 area during the course of several flights made on March 31, 1992. It was understood, that on the completion of the survey flights of the 31st, some microwave detection of seepage had been noted, but the activity was less than it had been several months earlier. That where previously it had been detected with a high level of activity in the middle of the field shown in Figs. A-2, the nearest activity was to the southwest. The new location for activity was blocked by trees and could not be observed from the radar location at SITE 1.

The APS radar operator/observer was given an opportunity to observe the displays for the ground-based system, and he did not report seeing activity of the type that he would associate with radar returns from seepage gases.

Since the ground in the local area was still damp from the rain, and more rain was forecast, a decision was made to move to SITE 2 in west Texas.

IMPRESSIONS

SITE 1 was useful, from the standpoint that it provided an initial opportunity to set-up equipment and to begin to work with the APS helicopter-radar group. The failure of the helicopter radar system to duplicate previous survey results for this area provided evidence that observations by prior investigators was correct. Rain and wet earth may well have worked to reduce the radar returns associated with the presumed presence of seepage gases.

SITE 2

GENERAL LOCATION - SITE 2 is in west Texas

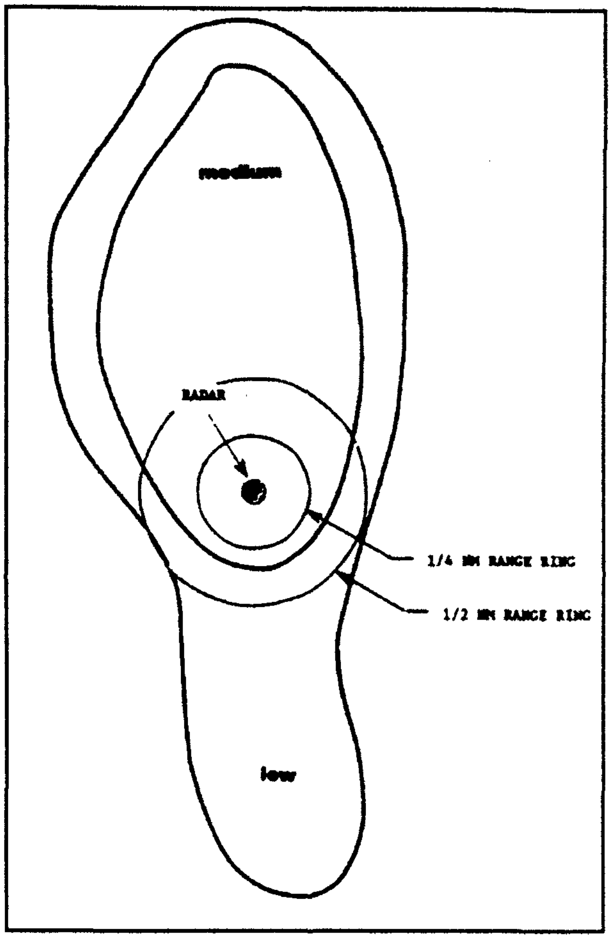

Fig. A6 Location of the ground-based radar relative to the helicopter radar-map of seepage gas at SITE 2.

In the above figure, the contour lines indicating levels radar video intensity are based on a helicopter survey made several months earlier. Note that SITE 2 had only a medium and low level contour, as compared to SITE 1 which additionally had a high level contour.

Again, similar to SITE 1, the ground-based radar was physically located within the area of the highest level of previously measured seepage gases.

DATES OF OPERATION

The ground-based radar system was set-up at SITE 2 on the morning of April 3, 1992. Initial observations began at about 10:00 local time, and included a variety of scans and recordings with the 6-ft array antenna. Operations at SITE 2 continued until about 12:00 on April 4, 1992. The system was then moved about 3/4 nm to SITE 3, for continued operations on that same day.

SITE DESCRIPTION

The terrain at SITE 2 was significantly different from that encountered at SITE 1. At SITE 2 the terrain was not flat. The ground had varying slopes, ridges, rock out-croppings, and dry stream beds. In the absence of rocks, the ground was dry, hard packed, red earth. Wooden tent stakes used to support guy-lines for the corner reflector support masts, were driven into the ground only with great difficulty.

A photograph of the terrain at SITE 2 is shown in Fig. A7. The immediate area is marked with sparse grass and low shrubs. In the photograph,approximately mid-way, right-to-left, between the windmill tower and the left border, a white vertical line (a wooden support mast) marks the location of a radar corner reflector, staked out at a range of 400 ft. Continuing along that line of bearing, at a range of 800 ft, there was a low rocky outcropping, and then the ground sloped downward into a dry stream bed. The elevation at the radar antenna was 21 ft higher than at the stream bed (at a distance of 3,000 ft). From 800 ft to about 4,000 ft clutter returns were absent, by reason of the depression. Beginning at about 4,000 ft, as a consequence of the relatively steep incidence angle between the radar line of sight and the slope of the local terrain, clutter returns from along that same bearing were quite strong.

As may be further seen from the photograph of Fig. A7, the scattered vegetation consisted of grasses, yucca, and mesquite. None in the immediate vicinity exceeding 6-ft in height.

WEATHER

Note in Table A3 which follows the first entry is for the date of April 3, 1992, when only a single set of readings was made. The remainder of the entries in Table A3 are for the date of April 4, 1992.

The low barometric pressure readings in the third column of Table A3, reflect that the local elevation was on the order of 4,400 to 4,500 ft. At SITE 1 in east Texas the elevation was on the order of 470 ft above sea level.

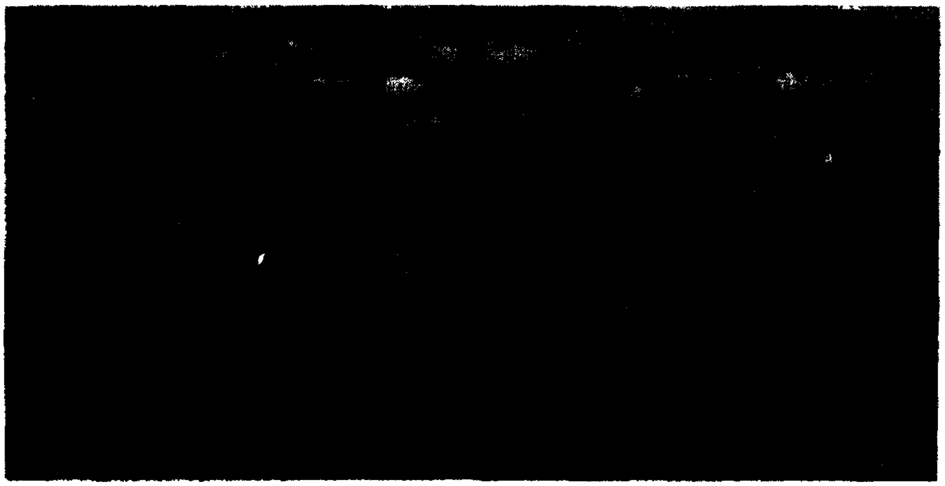

Fig. A7 West Texas SITE 2, the terrain from the radar antenna viewpoint.

TABLE A3

APRIL 3-4, 1992 WEATHER DATA

TIME	TEMP ° F	% RH	PRESS IN-HG	WIND DIR °	WIND KNOTS	NOTES
1641	70	36	25.96	180	4-6	10% CLOUDS
0650	30	>95	25.84	120	4-5	CLEAR
0930	57	42	25.98	-	0	SCATTERED CIRRUS
1045	65	27	25.98	180	0-4	50% CLOUDS
1230	74	22	25.37	45	8	20% CLOUDS
1330	72	27	25.4	315	8-9	50% CLOUDS
1450	67		25.39	180	6-7	50% CLOUDS

NOTE - the last three sets of weather data entered in the table above, were made at SITE 3, a location approximately 1 nm from SITE 2.

NARRATIVE

At SITE 2, the setup of the ground-based radar started at about 10:00 local time, and within an hour the radar was in operation. Time was taken in establishing geographic reference points - such as the several radar corner reflectors. The radar was exercised with both the scanning and pencil beam antenna - with most observations being performed with the scanning antenna.

At no time was there evidence, when using the pencil beam antenna, of returns that could be reasonably associated with elevated targets, except for birds. As was the case at SITE 1, large birds, mostly turkey buzzards were detected and tracked by radar at ranges in excess of 2 nm.

At SITE 2, both antennas were exercised. With the 6-ft scanning antenna, various gain and strobe intensity settings were exercised in an effort to recognize radar returns whose characterisitics matched those described by previous radar observers of gas seepage. With the pencil beam antenna, observations were made for a variety of fixed elevation angles, as well as for periods of "searchlighting" a specific bearing and elevation angle.

On April 4, 1992, the APS helicopter and radar arrived at SITE 2. On approaching SITE 2, the helicopter team conducted a re-survey of the area.

Based on previous surveys at SITE 2 by the APS team, the ground-based radar had been located within the area of highest radar returns. On April 4, 1992 the location of the ground based radar, according to the helicopter-radar survey made that date, was no longer in a region of detectable seepage gas returns.

The helicopter team identified a region 3/4 nm to the northwest as being the nearest region at which radar seepage returns were currently being observed. With that information, a decision was made to immediately move to a spot that would afford a better opportunity for observing the radar seepage returns.

INITIAL IMPRESSIONS

At SITE 2, the impressions and evidence was that the radar was operating normally.

The NRL observer/operators conducted numerous observations with the radar with a variety of combinations of gain settings, strobe intensity, scanning and searchlight, and with the pencil beam a variety of elevation settings. Results were negative in that none of the observed radar returns matched the characteristics of

signals that would be associated with radar detection of seepage gases.

The helicopter radar/observer-operator on observing the PPI display at the ground-based radar agreed that seepage returns were not evident on that display. Further, he indicated that based on his re-survey conducted earlier in the day, the nearest seepage returns that he had detected were approximately 3/4 nm to the north-northwest of SITE 2.

The impression gained was that for this particular date and time, SITE 2 was not suitable for further observations. The extent of radar detectable seepage, based on the helicopter system surveys had changed. The SITE 2 location, which had been chosen because it was within the perimeter of a medium level of radar measured seepage (Fig. A6), was on April 4, 1992, a location where neither the airborne or ground-based systems were successful in observing such returns. For reasons unknown, the helicopter determined perimeters for radar observation of seepage gas shown in Fig. A6 had changed.

SITE# 3

GENERAL LOCATION SITE 3 is in west Texas within 1 nm of SITE 2.

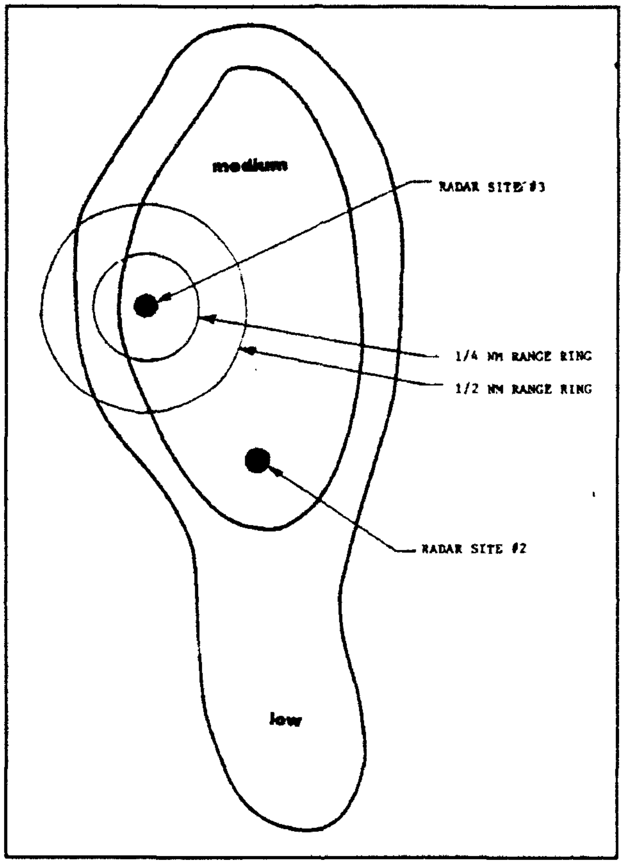

Fig. A8 Location of the ground-based radar relative to the helicopter radar-map of seepage gas at SITES 2 and 3.

Fig. A9 shows the ground based mobile laboratory vehicle and the APS helicopter at SITE 3.

DATES OF OPERATION

Operations at SITE 3 were conducted on the afternoon of April 4, 1992.

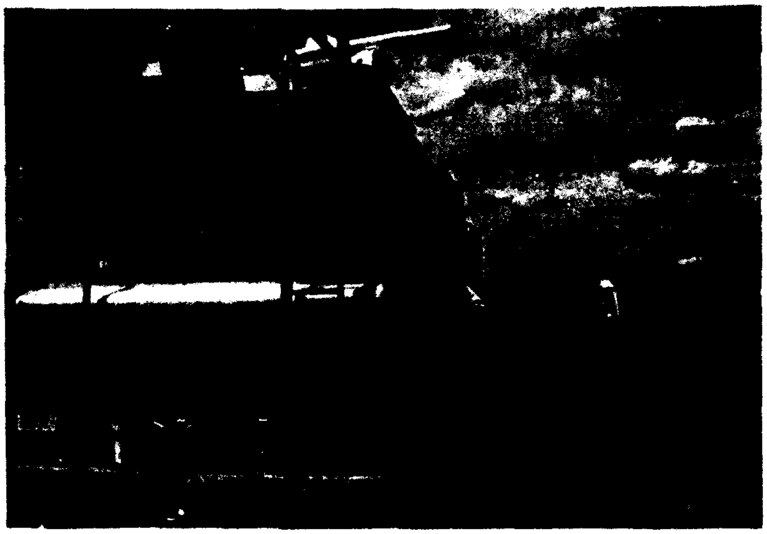

Fig. A9 The roadside location of the ground-based radar, used for the radar investigation of SITE 3.

SITE DESCRIPTION

The terrain at SITE 3 was in a wide stream valley trending east-west.

WEATHER

The weather data for SITE 3 is included in the data presented in Table A3. The weather can be described as sunny with scattered cumulus humilis, dry (22-27% RH) and with variable low winds (6-8 knots).

NARRATIVE

The ground-based radar was set-up at SITE 3, on the afternoon of April 4, 1992. SITE 3, was a location on the margin of a state road, and was within a mile of the SITE 2, location. The site was selected for the reason that it provided a potentially more favorable viewing aspect to a region of seepage gas than was possible from SITE 2. The more favorable aspects of the location were; one, it was within 1/2 nm of seepage claimed to have been observed during the most recent helicopter survey; and two, the location was situated such that the radar clutter return from slanting terrain was minimized.

Several hours were spent at this location in trying to duplicate the observations made several hours earlier in the day by the helicopter-borne radar.

As on previous days, the operation of the ground-based radar appeared to be perfectly normal. Operations were terminated after several hours for the reason that recognizable, unique radar returns of the type expected to be associated with the presence of seepage gases were not being detected with the ground-based system.

The impression gained was that for reasons unknown, the observers at the ground-based radar were unable to conclude that seepage related radar returns were observable from SITE 3.

SITE 4

GENERAL LOCATION - SITE 4 is in west Texas, about 6 nm north of SITES 2 and 3.

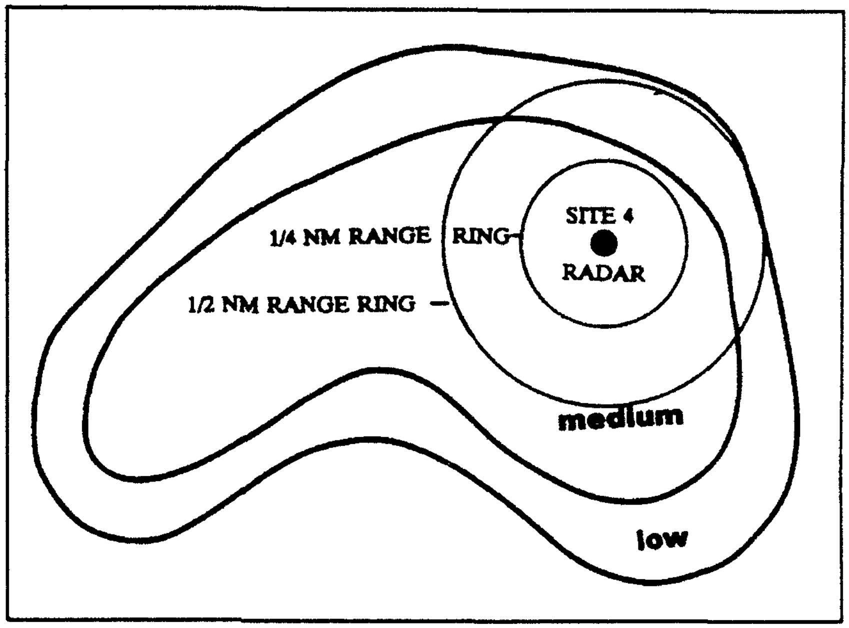

Fig. A-10 Location of the ground-based radar relative to the helicopter radar-map of video intensities at SITE 4.

In the above map, the location of the radar is on a grassy road shoulder.

DATES OF OPERATION

The ground-based radar arrived at SITE 4 at about 09:00 local time on April 5, 1992. After a successful day of joint operations with the helicopter, the ground based system was secured to allow personnel a day of rest.

Observations were resumed at SITE 4 on April 7, 1992 and continued through until about 15:00 the next day, April 8, 1992.

On April 9, 1992, on the start of a re-location of the ground-based radar to northwest Texas, another brief stop was made at SITE 4 for additional radar observations.

SITE DESCRIPTION

SITE 4 was distinct from the previous sites visited in that it was treeless and relatively flat, and had comparatively few cultural scatterers. Fig. A-11 and A-12 show two views of the terrain. In Fig. A-11 photograph shows a view, looking north, at the mobile-lab/radar location from a distance of about 300-ft.

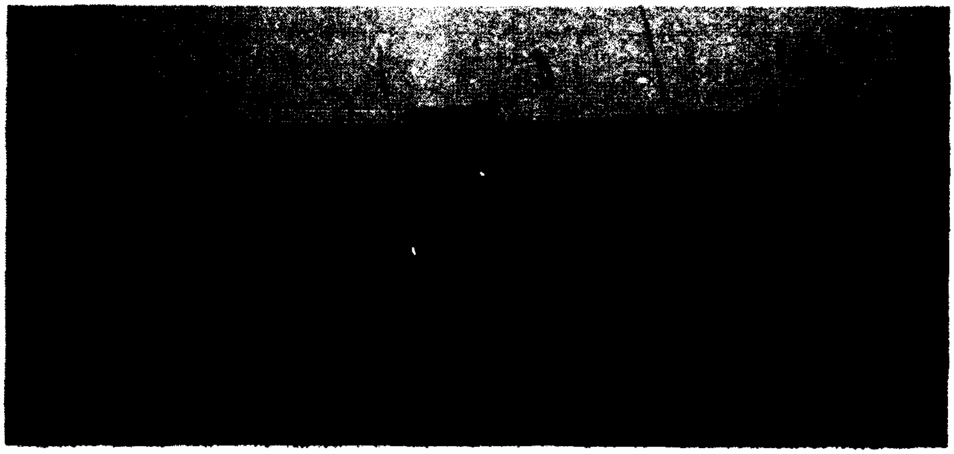

Fig. A-11 View looking north at SITE 4.

Fig. A-12 View at SITE 4 looking South.

In Fig A-12, the camera has been turned 180°and the view to the south is shown. From these two views it may be seen that the terrain is flat, that the predominant ground cover is grass with a scattering of yucca and other low, unidentified shrubs. About 1,200 ft south of the radar site a line of telephone poles ran in a generally east-west direction.

The soil in this region was hard-packed, dry, red earth. The land elevation at the radar site was 4,800 ft.

WEATHER

TABLE A4
WEATHER DATA FOR APRIL 5, 1992

TIME	TEMP ° F	%RH	PRESS. IN-HG	WIND DIR.	WIND KNOTS	NOTES
0900	53	80	25.03	180	4	OVERNIGHT SHWRS THIN HI OVERCAST BASE AT 2,000 FT
1000	51	80	25.07	180	4	THIN OVERCAST. SUN VISIBLE
1100	56.5	64	25.09	225	5-7	THIN OVERCAST NO SHADOW
1200	57	57	25.12	180	10-12	THIN OVERCAST NO SHADOW
1300	57	64	25.13	-	-	HIGH OVERCAST SCATTERED LAYERS
1445	54	-	25.11	135	16	STORM TO NORTH
1540						HEAVY RAIN/HAIL
1610	49	80	25.03	180	15	END .5-.75-IN RAIN
1720	48	-	25.07	235	3-4	-

In Table A-4, the entry made for the time 15:40, was made at a time when, for protection of equipment from power surges, all electrical power had been turned off. This was a time period when a severe thunderstorm passed over the area.

The several tables which follow account for the weather observed in or near SITE 4, during the several occasions when equipment was activated at that site and radar data acquired.

TABLE A5
WEATHER DATA FOR APRIL 7, 1992

TIME	TEMP ° F	% RH	PRESS. IN-HG	WIND DIR °	WIND KNOTS	NOTES
0945	66	50	25.16	315	1	CLEAR
1045	70	58	25.22	225	5	CLEAR
1232	78	35	25.25	225	5	FEW HI CIRRUS
1500	81	36	25.27	180	3	CLEAR
1745	81	38	25.28	180	5	CLEAR
2122	62	52	25.27	180	2	CLEAR
2236	58	61	25.27	45	8	CLEAR

TABLE A6
WEATHER DATA FOR APRIL 8, 1992

TIME	TEMP °F	SOIL TEMP	% RH	PRESS. IN-HG	WIND DIR.	WIND KNOTS	NOTES
0000	56		56	25.26	-	0	30-50% CLOUDS
0328	54		64	25.23	-	1	50% CLOUDS
0507	53		72	25.21	-	4	50% CLOUDS
0548	49		80	25.21	-	2	50% CLOUDS
0715	47		80	25.22	-	4	50% CLOUDS
0800	48		86	25.23	-	4	50% CLOUDS
0915	63		50	24.24	-	-	CLOUDY
1000	67	60	49	25.24	135	6	CLOUDY
1115	71	60	42	25.24	180	8	100% OVERCAST
1211	77	70	34	25.25	180	10	CLOUDY
1328	75	71	43	25.24	180	10	CLOUDY
1400	78	72	34	25.25	180	10	CLOUDY
1500	81	75	36	25.23	180	12	CLOUDY

TABLE A7
WEATHER DATA FOR APRIL 9, 1992

TIME	TEMP ° F	SOIL TEMP	% RH	PRESS IN-HG	WIND DIR	WIND KNOTS	NOTES
0837	55	-	72	25.16	-	-	CLEAR
0915	63	57	74	25.13	0	3	-
1049	80	78	46	25.95	315	5	-
1301	91	98	40	27.12	315	5	-

Beginning with Table A-6, a column has been added, to include surface soil temperatures.

Of the entries made in Table A-7 only the first two apply to SITE 4. The following two entries were made on the occasion of road-side stops to acquire radar data on specific types of grassy terrain and plowed fields.

NARRATIVE

On April 5, 1992 the ground-based radar was set-up at SITE 4, and was in operation by 09:00 local time. SITE 4, as pictured in Figs. A-11, and A-12 was situated in the middle of comparatively flat and treeless terrain. The elevation at the site was 4,800 ft.

The helicopter-borne radar arrived at about 10:00, and proceeded to make a number of flights in the area. On these flights, video PPI records were obtained. The primary survey flight path was similar to one flown several months earlier. It was a path that passed directly over the ground-based radar at SITE 4.

The helicopter-radar observer/operator was given the opportunity to observe the ground-based radar displays. He found the PPI display to be very similar to the type of display that he had observed earlier in the day when overflying the ground-based radar.

The helicopter-radar observer-operator played back for the ground-based team, his video camera records for the same field of view. At that time, based on relatively quick initial looks, there was agreement by both ground-based and airborne system observers that the two displays, single scan PPI displays, were quite similar. When

comparing successive PPI scans there was a significant difference.

With the airborne system, the comparison of successive scans, allowed for the sensing of the cross-over into regions with radar detectable seepage. On a practical basis, a similar capability could not be achieved with the ground-based system.

With the ground-based system, the fixed location provided a capability for comparing successive scans for that fixed location. That capability, in turn allowed for the determination of scan-to-scan changes, which are arguably, a superior method for the location of amplitude and range varying radar returns associated with seepage gases.

Both displays showed areas of distributed signal returns from areas to the northeast, and to the southwest of the ground-based radar site. The area to the southwest, covered a noticeably greater area than did the area to the northeast.

Fig. A-13 is an example of the display. The PPI photo is arranged so that North is at the top of the page. The range rings, which may not show in the printed reproduction on this page were set at 1/4 and 1/2 nm. Several parallel, almost horizontal lines may be seen at the center of the display. Those lines represent the radar returns from a highway, power lines, and railroad tracks. The distance from left to right margins is 1 nautical mile.

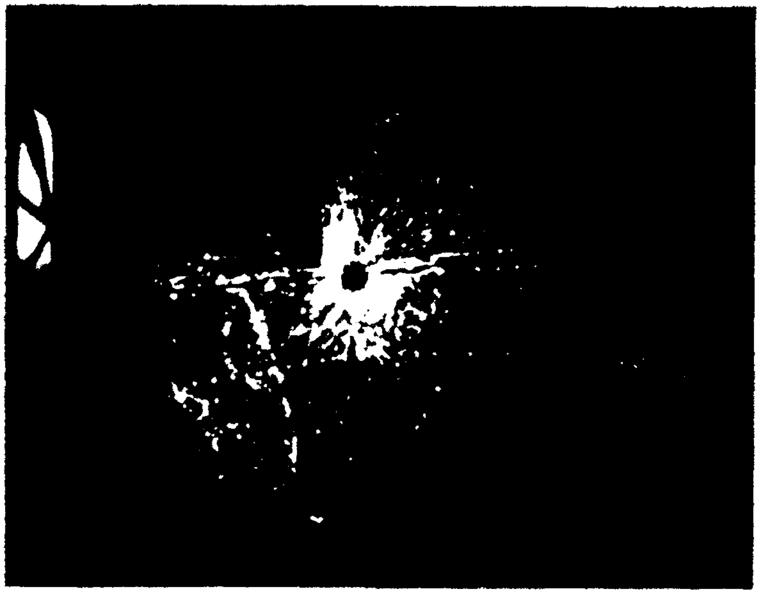

Fig. A-13 A PPI display for SITE 4. The distance from left to right edge of the display is equal to 1 nm.

In Fig. A-13, the 6-ft array was rotating at 20 rpm. Thus the photo in A-13 is the record for one scan of the radar antenna.

Fig. A-14 is an inverted A-scope display for this same SITE 4 region. The A-scope photo of Fig. A-14 is the record for a single radar transmitter pulse. In the example shown, the same antenna used in the scanning mode for Fig. A-13, was stopped and fixed to look out on a 228° line of bearing. Fig. A-15 is the same type of A-scope display, now processed to form a rising raster type A-scope display.

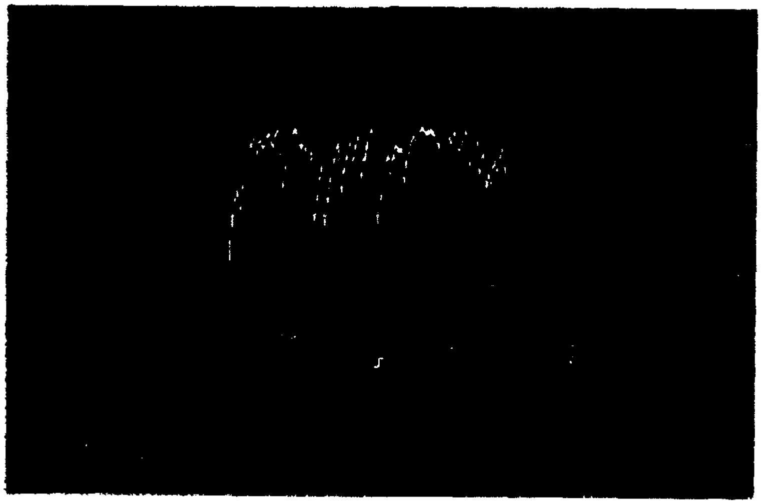

Fig. A-14. An A-scope display for SITE 4, 228° bearing.

In Fig. A-14 time is measured from left to right, The grid in the photo has 1 cm spacings. The time for the trace to travel from the left to right ends of the display is 5 μseconds, which corresponds to a radar range of approximately 5,000 ft. The start of the radar transmitter pulse in the fig. is at X = 0, and Y = 2.2 cm. A target is indicated at the point X = 2 and Y = 5. (Note this photo is an inverted image of a conventional A-scope display). Increasing range from the radar to a target is represented by displacement of the trace to the right. In Fig. A-14 signal amplitude is the distance from the top of the display to the trace. Thus the transmitter in the example shown has a relative amplitude of about 5.8 cm. The first major target, the one at X =2 and Y =5, has an amplitude of 3.0 cm.

It should be noted that the helicopter radar operator-observer has some benefits in that he is in a fast moving platform, so that the platform provides a mechanism for making some changes in signal amplitude more readily detectable than might otherwise be the case. The ground-based system utilized the A-scope as an adjunct to seeing subtle changes in both range and amplitude.

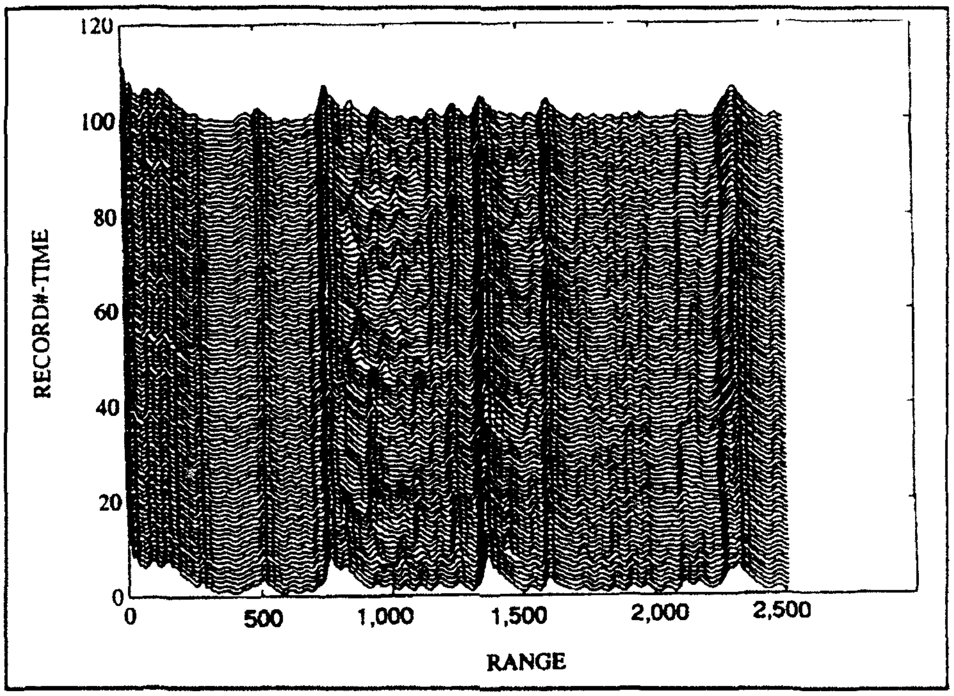

Fig. A-15 A rising-raster A-scope display for SITE #4, 223°bearing (same as Fig. 9).

In Fig. A-15 approximately 90 successive transmitter repetition periods are shown covering a period of about 1-second. Starting on the left side of the figure, the signal represented by the range 0 to about 250 ft, is a representation of the transmitter radiated pulse "leaking" through into the receiver. Note stability is indicated by each successive tracing being a replica of the preceding trace. A weak, but stable signal fixed in range may be noted at a range of 500 ft. Next there is a strong, yet stable signal at a range of 750. Between a range of about 750 and 1,350, there is a region where weak signals appear and disappear at differing times (time as measured on the vertical axis), and that their displacement in range is also varying. These irregular, range/time/amplitude variations are the type of signal characteristics which might be associated with radar returns from seepage gases.

These fluctuating signals gave an impression that these might be attributes of that would be associated with radar returns form seepage gases. Observing a specific target over a period of time, within a range of 500 to 1,600 ft from the radar, would result in the observation of amplitude variations of as much as an estimated 10 dB. These variations in amplitude and range were found in the region identified earlier by

the helicopter radar operator observer. The fluctuations continued right up until the time of shutting the system down for the approaching storm,

Within an hour of the acquiring the above encouraging data, and conferring with the helicopter operator/observer, operations were brought to a halt. A severe storm moved into the area. The storm was accompanied with multiple lightning strikes, heavy rain and hail.

About 30-45 minutes after the storm had moved beyond the radar site, the system was turned on. Observations were resumed. Immediately it was apparent that conditions had changed. The previously very dynamic display of variable targets or clutter within the 1/2 nm range was very different. Clutter amplitudes were very low, and there was not any perceptible variation to the clutter. After approximate 10 minutes, the formerly observed large amplitude fluctuations were again seen.

The day was marked as a considerable success, in that the ground-based system had approximately duplicated the success of the helicopter system. As the ground based group had been working steadily for 10 days without a break. A decision was made to take the next day off.

On April 7, 1992 several nearby sites were investigated before returning to SITE 4. Operations and observations were resumed at SITE 4 at about 17:45 on April 7, 1992. Conditions were much the same as they had been on April 5th. The amplitude and range variations were noted in regions to the southwest and the northeast of the radar, at ranges of from 750 to approximately 2,300-ft.

At about 18:00 local time, a nominal 24-hour period of observation was started. This was a limited effort in which one-person would periodically energize the system and make observations on the nature of the seepage related radar returns. The interesting result of this period of operation was that within a couple of hours after local sunset, the range and amplitude varying signals (signals at ranges of 500 to 2,000 ft) ceased. Fixed, discrete targets remained detectable throughout the night. The overall clutter level for the close-in targets dropped, such that the display on the PPI and the A-scope was frozen, except for those occasions when vehicles could be detected approaching or leaving the site. The display remained absent the range and amplitude varying signals until about 08:00 local time, when the variable signals began to build-up with the passage of time.

Meteorological conditions that were observed may have influenced radar performance. From being very dry, 38% RH and hot, 81 °F, at 17:45 local time, humidity increased and temperatures dropped during the night. Temperatures reached a low of 47 °F at 07:15 the next morning, at which time the humidity peaked at 86%.

A very heavy dew formed during this period, 07:00 to 08:00. The dew was not on the grass, but on the ground.

INITIAL IMPRESSIONS

SITE 4 was the location of the first ground-based radar observations which appeared to duplicate the helicopter-radar observations for what was claimed to be radar returns from seepage gases. SITE 4 approached an ideal, in that it was the flat terrain. Cultural scatterers were situated so as to enhance determinations of ranges and bearing, yet did not intrude into the areas of interest. The cultural scatterers were an east-west highway, railroad tracks, fence lines, and telephone lines.

The areas of interest were, to the northeast and to the southwest of the radar site.

The helicopter operator-observer, also noted that seepage gas associated returns were being observed, in essentially the same areas as observed on survey flights a couple of months earlier.

On landing next to the ground based radar, the helicopter operator-observer compared the two displays, ground-based and airborne, and was satisfied that the ground-based display was similar to, and did show returns from areas of gas seepage nearly identical to what had been seen and recorded minutes earlier in-flight on the helicopter.

The ground based operators made observations and recorded data, and then switched to the pencil beam antenna. There were no indications of returns which would be uniquely associated with elevated echoing cells. These observations suggest that for antenna with an elevation beamwidth of 2.7°, at a range of 500-ft a target would have to be elevated some 25 ft to be within the 3-dB beamwidth of the radiated beam. At 1,500-ft, an elevated target would have to be some 40 ft above ground to be within the 3-dB antenna pattern.

Returning to the fan beam antenna on the ground-based radar, observations were then made with the A-scope. The A-scope revealed that most of the many of the radar return signals, were fluctuating in amplitude, possibly by 10 or more dB. Further, the fluctuations were only associated with returns which were noted in the two previously referenced areas, to the northeast and to the southwest of the radar.

As data was beginning to be acquired for this site, a severe storm system moved into the area. When only a few miles away, the radar was turned off, as there was heavy lightning activity. The storm passed overhead in a period of 30-45 minutes

time. During that time there were winds gusting to over 30 knots, an accumulation of rain of an estimated 1/2 to 3/4-inch, and two periods of heavy hail, of up to 3/8-in diameter.

After waiting an additional 30 minutes for the storm to move further away, the radar system was turned "on" again. Almost immediately, the observers were impressed by the A-scope display which showed all ground clutter within 1/2 nm reduced in amplitude as compared to values observed before the storm. Also, for that clutter which could be observed, the amplitudes were very stable.

Over an approximate 10-minute period of observation, commencing shortly after turning the radar "on." The clutter signals began to build-up in amplitude and exhibit the strong amplitude variation observed prior to the storm.

This event of the storm, the initial reduction in the amplitude and variability of the close-in clutter (500 to 2,000-ft) and then the restoration to pre-storm amplitudes and variability, seemed to "fit" with the oral history of the impact of rains on the radar observation of seepage associated radar returns.

The first day of observation at SITE 4 concluded with confidence that the ground based radar was successfully duplicating the performance of the helicopter borne system. Additionally, for the first time, unique radar returns were received for specific ranges and bearings predicted by the helicopter-radar system

As the ground personnel had been working some 10 days without rest, a 24-hour break was declared. Two days later, and after acquiring data at other nearby locations, the ground based radar resumed operations at SITE 4.

At 17:45, on April 7, 1992 , a 24-hour period of radar observations was started at SITE 4. Because of the limitations on personnel and fuel, the intent was to periodically take data during the night, and to then resume a more complete routine with daylight and the availability of additional personnel.

Starting at 17:45 in the afternoon of April 7, 1992, signals similar to the previously observed variable signals were observed at ranges of from 700 to 1,500 ft. By time 21:22, the variable signals had ceased, and overall clutter levels were down. similar to what had been observed immediately after the passage of the rain storm.

Note the record in Table A-5 which shows the temperature dropping from 81°F at time 17:45 to 62° F at time 21:22. The next morning a temperature low of 47°F was reached at 07:15. Note also that for these same time periods the relative humidity went from 38% to 52%, and then to 61%.

The record then shows that the strongly varying, near-in clutter, began to decrease at about the time of local sun-down. Further, that with the peaking of the humidity build-up in the morning, and the occasion of a very heavy dew, the variable and strong, close-in clutter levels returned to the previous daytime levels and characteristic variability.

Later in the day, on April 7, 1992, several hours were spent in trying to identify specific sources of discrete close-in clutter echoes. It is to be noted that humans were used as reference targets in some of the observations - in that various personnel were directed too and observed on the A-scope as they moved within the illuminated area.

Humans as targets and a corner reflector, proved to be very unsatisfactory because of multi-path caused variations in received signals. These targets were of use only in establishing reference bearing angles to specific discrete targets, and in setting up a north reference for the antenna bearing.

An example of a discrete target determination is to be seen by reference to Fig. A-12, the two bushes in the middle background. In close-up in Fig. A-16 they are shown below.

Fig. A-16 Two yucca plants at SITE 4, observed as discrete targets.

The yucca plants typically provided returns of the type seen at a range of 700 ft in the A-scope display of Fig. A-14.

It should be noted that SITE 4 was the location of radar observations on 4 separate occasions. As has been reference earlier. Observations were made on:

(a) April 5, 1992 - Joint observations with the helicopter radar. Agreement in seeing the same fluctuating returns. These were returns

were helicopter-system associated with the presence of seepage gases.

(b) April 7-8, 1992 - Observations at SITE 4 for the purposes of monitoring diurnal variations for a 24-hour period.

(c) April 9, 1992 - Brief period of observations, with the ground-based system configured for in motion "on the road" observations while enroute to the SITE 8 (cattle feed lots). Observed fluctuations were similar to those observed on the previous day.

With the positive results from the fixed-ground radar at SITE 4 it was decided to mimic an airborne survey. This was accomplished by mounting the antenna on the mobile-lab roof and driving at 45 MPH on an east-west paved highway through the anomaly shown in Fig. A10. Several passes in both directions were made during the course of two of the days of operation in the vicinity of SITE 4. Fluctuations associated with the boundaries of the airborne mapped anomaly were not detected. The range and amplitude varying radar signals of interest detected with the ground based, fixed radar at SITE 4, were not successfully detected when the same area was observed with the ground based radar (the mobile lab) traveling at 45 MPH.

SITE 5, 6, & 7

Both SITE 5 and SITE 6 were close to SITE 4, but outside the area of gas seepage as previously surveyed with the helicopter-borne radar system. The weather and terrain description is covered in the material presented for SITE 4, for the date of April 7, 1992. SITE 7 was south of SITE 6 and 2 miles from SITE 4.

The notes of significance for these three sites, are that some degree of fluctuating signal return was seen for each of these locations. Each of these three locations are outside the areas identified in the airborne radar video intensity map of Fig. A-10. Note SITES 5 and 6 were on an east-west line relative to SITE 4. SITE 7 was to the south of SITE 4. These locations were in helicopter mapped regions which had indicated that they were outside of the area of detectable seepage gas associated radar returns.

These above noted observations were somewhat unexpected. Questions which occurred, and which can not be answered at this time are: Were these seepage gas related returns that were missed in the earlier helicopter survey? Were they returns from new seeps? Were these new returns associated with seepage gases at all, or might they have been returns from convective cell activity generated by something other than seepage gases?

SITE 8

GENERAL LOCATION - SITE 8 is in northwest Texas. The reason for visiting this location is that the APS airborne radar observers regard feedlots as benchmarks which provide very strong seepage gas type radar returns. The supposition being that the radar returns were reflecting the presence of cattle generated methane and possibly ammonia.

The site was rolling terrain, with some grasses. The elevation was 3,500 ft. The cattle feed lots were very area extensive, stretching over 5,000 by 1,500 ft. The lot was broken into many large rectangular pens, each probably capable of holding several hundred head of cattle. The pens were made of metal posts of about 3-in diameter, 5 ft high. Fig. A- 17 is a view of the cattle pens

The radar detectability of cattle generated methane, was regarded as another step in confirming the sensitivity of, and the validity of using a radar for sensing the presence of gases, hydrocarbon gases.

At SITE 8, both the pencil and fan beam antennas were used. The pencil beam was exercised and used to determine the possible presence of radar returns from elevated gases or convective activity. No such activity was detected.

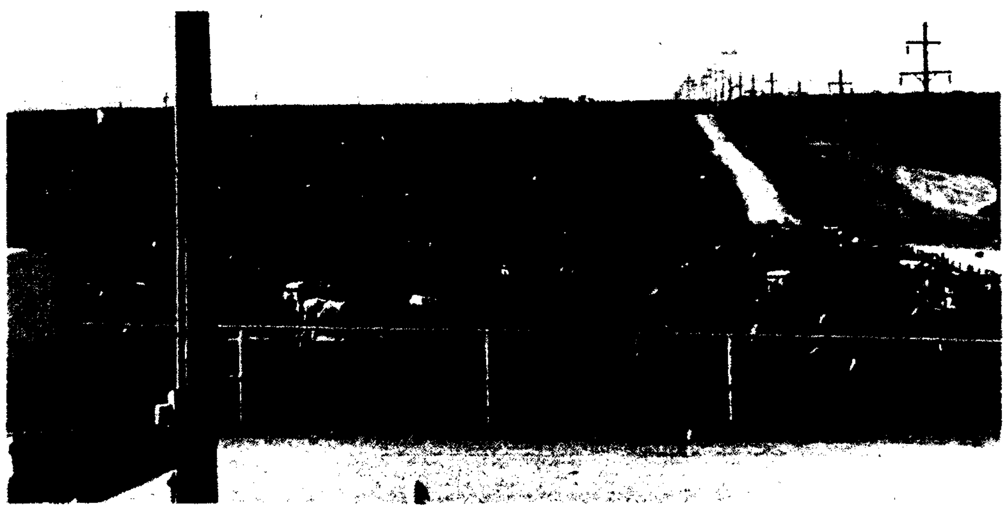

Fig. A-17 Cattle feed lot in northwest Texas, the white object centered on the left edge of the photograph is a part of the fan beam radar antenna.

APPENDIX B
RADAR SYSTEM PARAMETERS

Two similar but different radar systems are referenced in this report. Both systems were manufactured by Raytheon.

The system flown in the APS helicopter was a Raytheon Model 2700, vintage of the early 1970's. The system used by NRL for the ground-based investigation was a Raytheon Model R-82, vintage 1990's.

Key parameters and characteristics of the two systems are presented in the table below.

TABLE B-1
RADAR SYSTEMS CHARACTERISTICS

ITEM	MODEL 2700 PATHFINDER	MODEL R-82
FREQUENCY, MHZ	9410 ± 45	9410 ± 30
PEAK POWER, KW	5	25
PULSE LENGTH, SEC	.08/0.4	.08/.25/.75/1.0
REP. RATE, PPS	1,500	2,000/1,000/750/500
POLARIZATION	HORIZONTAL	HORIZONTAL
HORIZ. BEAMWDTH	3	1.2/2.7 *
VERT. BEAMWDTH	20	25/2.7 *
SIDELOBES, DB	± 10°,-20	± 10°,-26
SCAN RATE, RPM	23	20
RCVR NF	<10 DB	<6 DB
WEIGHT, LBS	69	86

*The first value shown is the 3 dB beamwidth for the R-82 fan beam antenna. The second value is the associated 3 dB beamwidth for the pencil beam antenna.

During the course of the subject investigation of seepage gas, it is understood that the helicopter radar system was used exclusively in the short pulse (80-nanosecond pulsewidth) mode, with the a pulse repetition frequency of 1,500 Hz, and a maximum display range of 0.5 nm on the Plan Position Indicator (PPI).

The ground based system was used, almost exclusively with an 80-nanosecond pulse width, a repetition rate of 2,000 pps, and with a PPI display range of 0.5 nm. On occasion the ground based system was exercised at ranges of up to 40 nm.

The Model 2700 radar (the helicopter system) used a display unit with an intensity modulated, rotating strobe to develop the PPI display. The R-82 also presents a PPI display, but the video data was digitized, and then displayed via a raster scan, in a manner similar to that used for TV receiver displays.

During the course of this subject investigation, the several operators expressed a marked preference for the older display as it allowed the operator to constantly look for and associate targets with the instantaneous pointing direction of the rotating antennas. With the raster scan, the immediate sense of where the antenna was pointing at any given instance was essentially lost. So for the type of investigation being conducted, the raster scan system used with the ground-based radar was regarded as inferior to the display system available to the operator/observer on the helicopter.

The ground based system was modified by NRL and provided with two capabilities not included with the airborne radar system. The two modifications were (1) the incorporation of an A-scope display, and (2) the ability to switch from a fan beam to a pencil beam. Included with this last modification, was an ability to vary the elevation of the radiated beam, as well as an ability to stop and "searchlight" specific azimuth and elevation bearings.

The pencil beam antenna system provided the ability to probe in elevation. The objective of its use was to determine if radar returns of interest were returns from elevated targets, such as a buoyant convective cell. The ability to distinguish between a ground based vice an elevated target with the available fan beam antenna was not regarded as practical.

APPENDIX C
RADAR CROSS SECTION

A rudimentary calibration of the R-82 radar, as used for the April 1992 observations in Texas was performed at West Field, NRL Chesapeake Bay Detachi.ient (CBD). The reference target was an 8-inch diameter aluminum sphere. At a range of 350-ft, the receiver gain control was adjusted (in a manner similar to that used in Texas) to achieve a receive signal-to-noise ratio (SNR) of 20 dB.

The form of the radar equation used in the computation of radar cross sections follows:

$$R_{max} = \left(\frac{P_k * G_t * G_r * \lambda^2 * \sigma_t}{L * BW * NF * S/N * K} \right)^{(1/4)}$$

where R = range

P_t = peak power

G_t = antenna transmit gain

G_r = antenna receive gain

λ^2 = wavelength squared

σ_t = target radar cross section

L = losses

BW = bandwidth

NF = receiver noise figure

S/N = received signal-noise ratio

K = conversion factor

For ease of computation the following logarithmic form of the equation was used:

$$40*LOG\ (R_{nmi}) = 10*LOG\ (P_k) + 10*LOG\ (G_t) + 10*LOG\ (G_r) + 20*LOG\ (\lambda)$$
$$+ 10*LOG\ (\sigma_t) - L - 10*LOG\ (BW) - 10*LOG\ (S/N) - K$$

With an operating frequency of 9410 MHz, the radar cross section of the 8-inch diameter sphere is equal to the intercepting or projected area cross of the sphere.

$a = \pi * r^2$ where $r = 0.1016$ meters (4-inches)

$a = 0.0324$ square meters

A sample calculation for a single pulse maximum range estimation is shown below (NAFI Pub TR-1554, Ref. 5):

Parameter	Value	Units	dB Representation	Multiply by	Add dB Results
P_k : Peak Power	25	KW	14.0	1	14.0
λ : Wavelength	3.19	CM	5.0	2	10.0
σ_t : Target RCS	0.0324	M^2	-14.9	1	-14.9
G : Antenna Gain	33.7	DB	33.7	2	67.4
L : Losses	57.4	DB	57.4	-1	-57.4
B : Bandwidth	15	MHZ	11.8	-1	-11.8
NF : Noise Figure	6	DB	6	-1	-6.0
S/N : Signal/Noise	20	DB	20	-1	-20.0
Conversion Factor	30	DB	30	-1	-30.0

4 dB nautical miles $= SUM_{4R} = -49.6$ dB

$R = 0.0575$ nm $= 350$ ft

The array antenna had a free space gain of 28.5 dB. When used at a height of

14-ft above ground, the maximum range for targets within the first three elevation lobes is increased about 1.8 time the free-space range. A 1.8 increase in range is equivalent to an approximate 10.4 dB increase in power or a 5.2 dB increase in one-way antenna gain. The gain for the lower elevation lobes was then about 33.7 dB.

The measurements at CBD were used to establish an effective overall loss parameter that could be used for subsequent determinations of signal-to-noise ratios to be expected for variations in target cross section and/or ranges. It is to be noted that the receiver gain setting for the above range and loss determination was the relative 09:15 (potentiometer dial setting) used for most of the Texas data.

The R-82 fan beam antenna lower multipath antenna lobes, those with lobe maxima at 0.1°, 0.3°, and 0.5°, were confirmed during the CBD antenna calibration measurements.

Once having established the losses associated with the radar system, for the lowest elevation lobe, the expected signal-to-noise ratios for other targets at various ranges in that lower elevation lobe were then calculated, and plotted Fig. 13 of the main report.